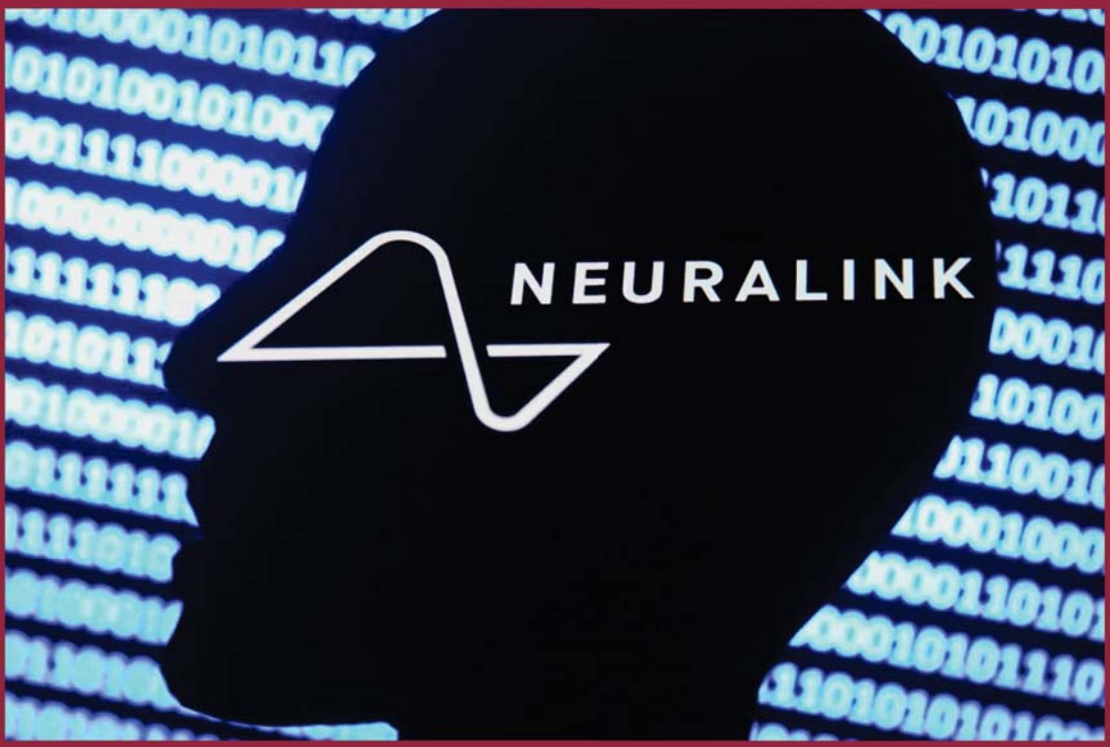
Brain Implant

The Research Supporting Neuralink



Fouad Sabry

BERSERKER
BOOKS

Brain implant

The research underpinning Neuralink

F. Sabry

Introduction

How did I write this book?

In each book of *The Encyclopedia of Emerging Technologies*, I aim to gain immediate, raw search insights, straight from the minds of people trying to answer their own questions about the emerging technology.

There are 3 billion Google searches every day, and 20 per cent of them have never been seen before. They're like a direct line into people's thoughts.

Sometimes it's 'How do I clear a paper jam?'. At other times, it's the heart-wrenching fears and secret longings that they would only ever share with Google.

In my quest to uncover an untapped goldmine of content ideas relating to 'brain implants', I use a range of tools to gather autocomplete data from search engines such as Google, and then quickly extract every useful phrase and question that people ask in relation to the keyword 'brain implant'.

It’s a goldmine of human insights that I can use to create fresh, extremely useful content, products and services. Friendly people like you really want this.

People’s searches are the most important dataset ever collected on the human psyche. Therefore, this book is a living product and is constantly updated with more and more answers to new questions about ‘brain implants’, asked by people like you and me who are curious about this new, emerging technology and want to learn more about it.

My approach to writing this book is to gain a deeper understanding of how people search for information on ‘Brain Implant’, to uncover questions and queries that I wouldn’t necessarily think of off the top of my head, and to answer these questions in super simple and easy-to-understand language, whilst making the book easy to navigate.

So, when it comes to writing this book, I’ve made sure it’s as optimised and focused as possible. The purpose of this book is to help people further understand and expand their knowledge of ‘brain implants’. I aim to answer people’s questions as accurately as possible and provide much more insight.

It’s a fantastic and wonderful opportunity to explore and directly address the questions and concerns people have, and to bring insight, validation and creativity to the book’s content – even pitches and suggestions. The book uncovers rich, less crowded and sometimes surprising areas of research inquiry that I would not otherwise have reached. There is no doubt that, once read using this approach, the book is expected to enhance the knowledge of potential readers.

I have adopted a unique approach to ensure the content of this book always feels fresh. This approach relies on listening to what people are thinking by using search listening tools. This approach has helped me:

Meet readers exactly where they are, so that I can create relevant content that strikes a chord and fosters a greater understanding of the subject.

Keep my finger firmly on the pulse so that I can receive updates when people are talking about this emerging technology in new ways, and monitor trends over time.

Uncover hidden treasures of questions that require answers regarding this emerging technology, to discover unexpected insights and hidden niches that boost the content's relevance and give it a competitive edge.

The framework for writing this book includes the following:

(1) I've stopped wasting time relying on gut instinct and guesswork about what content readers want; I've filled the book with what people actually need, and I've moved away from endless content ideas based on speculation.

(2) I've made sound decisions and taken fewer risks to secure a front-row seat to what people want to read and know – in real time – and used search data to make bold decisions about which topics to include and which to exclude.

(3) I've optimised my content production to identify content ideas without having to manually sift through individual opinions, saving days and even weeks of time.

It’s wonderful to help people expand their knowledge in a simple way, simply by answering their questions.

I think the approach taken in writing this book is unique, as it focuses on the key questions asked by readers in search engines.

Epigraph

Brain implants are technical devices that are directly connected to the brain of a biological subject. These devices are often placed on the surface of the brain or attached to the cerebral cortex. Brain implants are sometimes also referred to as neural implants. The development of a biomedical prosthesis capable of bypassing regions of the brain that have become dysfunctional as a result of a stroke or other head trauma is one of the main objectives of contemporary brain implants, and is also the focus of most research currently being carried out. This involves the replacement of a sense, as in the case of sight. In animal experiments, other types of brain implants are sometimes used solely for the purpose of recording brain activity for scientific purposes. The creation of interfaces between neural systems and computer chips is required for some types of brain implants. This research is being carried out as part of a broader field of research known as brain-computer interfaces.

Table of Contents

Foreword

Introduction

Acknowledgement

s Dedication

Epigraph Table of

Contents

Chapte 1: Brain Implant
r

Chapte 2: Cyberware
r

Chapte 3: Brain-Computer Interface
r

Chapte 4: BrainGate
r

Chapte 5: Neuroprosthetics
r

Chapte 6: Remote-controlled animal
r

Chapte 7: Neural Engineering
r

Chapter 8: Single-device recording

Chapter 9: Hybrot

Chapter 10: Mark Gasson

Chapter 11: Visual

Prosthesis

Chapter 12: Microelectrode Array

Chapter 13: Cyborg

Chapter 14: Neurotrophic Electrode

Chapter 15: Hippocampal

Prosthesis

Chapter 16: Brain Technology

Chapter 17: Stent-electrode recording array

Chapter 18: Chronic electrode implant Chapter

19: Cortical implant

Chapter 20: Neuralink

Chapter 21: Neural Dust

Epilogue

Chapter 1: Brain Implants

Brain implants are technical devices that are directly connected to the brain of a biological subject. These devices are often placed on the surface of the brain or attached to the cerebral cortex. Brain implants are sometimes also referred to as neural implants. The development of a biomedical prosthesis capable of bypassing regions of the brain that have become dysfunctional as a result of a stroke or other head trauma is one of the main objectives of contemporary brain implants, and is also the focus of most research currently being carried out. This involves the replacement of a sense, as in the case of sight. In animal experiments, other types of brain implants are sometimes used solely for the purpose of recording brain activity for scientific purposes. The creation of interfaces between neural systems and computer chips is necessary for some types of brain implants. This research is being carried out within the context of a broader field of research known as brain-computer interfaces. (Research into brain-computer interfaces also involves the development of technologies such as

electroencephalogram arrays, which enable communication between the human mind and a machine but do not require the surgical implantation of a device.)

Deep brain stimulation and vagus nerve stimulation are two examples of the increasingly common use of neural implants in the treatment of Parkinson’s disease and clinical depression, respectively.

Implants in the brain can either stimulate or inhibit electrical activity.

Since 1970, enormous progress has been made in research into sensory replacement. In the field of vision in particular, thanks to an improved understanding of how the visual system works, eye implants (which often involve some form of brain implant or monitoring) have been used and have proved successful. Direct stimulation of the auditory nerve is achieved through the use of cochlear implants to restore hearing. Although it is part of the peripheral nervous system, the vestibulocochlear nerve has an interface very similar to that of actual brain implants.

Recordings taken over an extended period from the brains of animals have been successfully carried out through several research endeavours. Action potential recordings of signals from the motor cortices of rhesus macaques were made as early as 1976 by researchers at the NIH, led by Edward Schmidt, using fixed ‘hatpin’ electrodes. These recordings included recordings from individual neurons for more than 30 days and consistent recordings for more than three years from the best electrodes.

In the Cyberkinetics version of the Utah array, the ‘hatpin’ electrodes are made of pure iridium and are insulated with Parylene. These are both materials currently in use.

Other research groups in the laboratory are developing their own implants to provide capabilities not available in commercially available products. A number of research organisations are currently working with human subjects to test basic motor prosthetic implants. Due to the relatively short lifespan of the implants, the duration of this research is currently limited to a few months. The array has now been incorporated into the Braingate as a sensor component.

A great deal of research is also being carried out into the surface chemistry of neural implants, with the aim of developing products that minimise any adverse effects an active implant may have on the brain, as well as any adverse effects the body may have on the implant's function. This research is being conducted to develop products that minimise all these effects.

Prosthetic neural memory silicon chips are another type of neural implant currently being researched and developed. These chips mimic the signal processing carried out by healthy and active neurons, enabling the human brain to form long-term memory.

In 2016, researchers at the University of Illinois at Urbana-Champaign reported that they had developed tiny brain sensors that could be used for post-operative monitoring and would dissolve once they were no longer needed.

The Defence Advanced Research Projects Agency (DARPA) has shown an interest in creating 'cyborg insects' that would be capable of transmitting data collected by sensors surgically inserted into the insect's pupal stage

. The insect’s movement would be controlled by a microelectromechanical system (MEMS), and it could theoretically survey an area or detect bombs and gas.

In 2015, it was reported that researchers at the Perception and Recognition Neuro-technologies Laboratory at Southern Federal University in Rostov-on-Don proposed using rats with microchips implanted in their brains to detect explosive devices. These researchers were from the Perception and Recognition Neuro-technologies Laboratory.

Since 1997, neurostimulators have been used to treat patients suffering from a wide range of neurological disorders, including epilepsy, Parkinson’s disease, dystonia and, more recently, depression. An unprecedented number of people suffering from severe neurological and behavioural disorders are finding relief as a direct result of rapid improvements in neurostimulation technology. Electrical stimulation is used in both invasive and non-invasive forms of neurostimulation therapy. These treatments are used to control neuronal function within a circuit.

Brain implants are also being investigated by DARPA as part of the Reliable Neural-Interface Technology (RE-NET) programme. This programme was launched in 2010 to directly address the need for high-performance neural interfaces to control the sophisticated functions enabled by DARPA's advanced prostheses. DARPA's advanced prostheses have enabled users to perform a wider range of functions than ever before. The aim is to provide a control interface for these limbs that is both high-bandwidth and easy to understand.

People such as Elon Musk, Bill Gates, Mark Zuckerberg and Jeff Bezos, as well as companies such as CTRL Labs, Synchron, the Massachusetts Institute of Technology and the University of California, San Francisco, are researching brain-computer interfaces.

Tungsten, silicon, platinum-iridium and even stainless steel are some of the materials used to manufacture modern brain implants. In the not-too-distant future, brain implants could be made from more unusual substances such as tiny carbon fibres (also known as nanotubes) and polycarbonate urethane. Almost all implants require surgery on the

open brain, but in 2019 a start-up called Synchron successfully implanted a brain-computer interface via the blood arteries. This is a significant breakthrough in the field of neurotechnology.

The electrical stimulation of dogs' brains, as demonstrated by Eduard Hitzig and Gustav Fritsch in 1870, proved capable of inducing movement. In 1874, Robert Bartholow demonstrated that the same was true for humans. Fedor Krause began his systematic mapping of human brain regions at the turn of the 20th century, using patients who had just undergone brain surgery.

The 1950s were notable for the volume of research carried out. Robert G. Heath conducted experiments on people with mental health conditions to alter the participants' state of mind through electrical stimulation.

Jose Delgado, a physiologist at Yale University, was able to demonstrate a certain degree of control over the behaviour of animals and humans through the use of electrical stimulation. He developed the Stimoceiver, also known as a transdermal stimulator, a device that is surgically implanted into the skull and

sends electrical impulses to the brain. These impulses influence fundamental behaviours and experiences such as aggression and pleasure.

Delgado later wrote a bestseller on mind control entitled *Physical Control of the Mind*, in which he made the following claims: “It has been demonstrated that it is possible to exercise remote control over the behaviour of a range of different animal species [...] The ultimate aim of this study is to provide an understanding of the processes involved in the targeted management of animals, as well as the development of practical solutions suitable for application in the field of human endeavour.”

In the 1950s, the CIA was also responsible for funding research into various methods of mind control, such as the MKULTRA programme. It has been speculated (though not verified) that, in addition to funding for some studies from the United States Office of Naval Research, Delgado received support from the CIA. Perhaps this is because he received funding from the US Office of Naval Research for some of his research. In an essay published in *Scientific American* in 2005, he rejected this claim and

described it as nothing more than the wild speculation of conspiracy theorists. He stated that the sole reason for his research was a gradual progression towards a more scientific understanding of how the brain functions.

The aim of the research currently being carried out is to give paralysed people the ability to control external devices with their thoughts and to enable members of this population group to convert their thoughts into text.

In a groundbreaking study published in *Nature* in 2012, two patients with tetraplegia were connected to the BrainGate neural interface system, proving that they could operate robotic arms through thought. The work was led by a pioneer named Leigh Hochberg, MD, PhD. Both participants were able to reach for and grasp objects located in three-dimensional space, and one of the participants used the system to pour herself a cup of coffee for the first time since becoming paralysed nearly 15 years ago.

Using the Stentrode brain-computer interface, two patients were able, in October 2020, to remotely operate a Surface Book 2 running Windows 10 and use their thoughts to send texts and emails, shop online and carry out financial transactions. This was the first time that a brain-computer interface had been implanted via the patient's blood vessels, meaning that open-brain surgery was not required.

Who the best candidates are for brain implants, and what the appropriate and inappropriate uses for neural implants are, are two of the ethical issues that have been highlighted. Although deep brain stimulation is becoming increasingly common as a treatment option for people with Parkinson's disease, there is a possibility that patients may experience certain behavioural side effects.

Apathy, hallucinations, compulsive gambling, hypersexuality, cognitive impairment and depression are some of the possible side effects, according to reports in the relevant literature. On the other hand, these side effects may be temporary and linked to the correct positioning and

calibration of the stimulator; as a result, they may be reversible.

Others, particularly bioconservatives, regard brain implants as unnatural and believe they lead to humanity losing essential human characteristics. However, some transhumanists, such as Raymond Kurzweil and Kevin Warwick, view brain implants as part of the next step in human progress and evolution. Biohackers are among these transhumanists. It sparks debate in a manner comparable to that caused by other forms of human augmentation. For example, one school of thought argues that implant technology would essentially transform humans into cybernetic entities (cyborgs). Furthermore, all research is expected to be conducted in accordance with the Declaration of Helsinki. Furthermore, standard legal obligations apply, such as informing the person wearing the implants and ensuring that the decision to receive implants is a free choice, with (almost) no exceptions. See

Other causes for concern include the possibility that brain implants could be misused, hacked or poorly constructed

, which would make them more vulnerable to cybercrime or invasive surveillance.

Brain implants are now part of modern culture, but there were early philosophical references of relevance dating back to René Descartes.

In his work entitled *Meditations*, published in 1641, René Descartes argued that it would be difficult to determine whether all seemingly genuine experiences were in fact fabricated by a malevolent demon with the aim of misleading us. The ‘brain in a vat’ thought experiment offers a contemporary interpretation of Descartes’ argument. This thought experiment imagines a brain that is kept alive, separated from its body, in a vat of nutrients and connected to a computer capable of stimulating it in such a way as to create the illusion that everything is normal.

In the 20th century, a widespread trend emerged in the genre of popular science fiction centred on ‘mind control’ and ‘brain implants’. These stories often took a dystopian perspective. The theme was explored in depth in fictional works written in the 1970s

. One such work is Michael Crichton's *The Terminal Man*, in which a man suffering from brain damage receives an experimental surgical brain implant designed to prevent seizures. However, he misuses the implant by triggering seizures for his own amusement. Another example of this can be found in the works of the science fiction author Larry Niven, specifically in the stories he wrote for the anthology *Known Space*.

Algis Budrys's book *Michaelmas*, published in 1976, presents a somewhat more optimistic perspective on the use of brain implants to connect to a computer as a form of enhanced intelligence.

An early theme that emerges is people's concern that the technology could be misused by both the government and the military. In the 1981 British television series *The Nightmare Man*, the pilot of a high-tech micro-submarine has a brain implant that connects him to his vessel. However, when the pilot removes the implant, he transforms into a terrifying murderer.

William Gibson's book *Neuromancer*, published in 1984, is widely regarded as one of the most important works of fiction to explore the theme of brain implants. This was the first book

to be written in what later became known as the ‘cyberpunk’ genre. A computer hacker is the protagonist of this story, which is set in a future where mercenaries are enhanced with brain implants to boost their strength, eyesight, memory and other abilities. Gibson is also credited with coining the term ‘Matrix’ and introducing the concept of ‘plugging in’ via scalp electrodes or direct implants. Furthermore, he explores the potential applications of brain implants in the entertainment industry, including the ‘Simstim’, also known as simulated stimulation, a device for recording and replaying events. Since Gibson’s work, the number of references to brain implants in popular culture has increased significantly. His influence can be seen, for example, in the role-playing game *Shadowrun*, published in 1989, which adopted his term ‘datajack’ to refer to a brain-computer interface. Johnny Mnemonic, published in 1995, and the Matrix trilogy, which was released later, were both inspired by the implants that appeared in Gibson’s books and short stories.

The ‘Typers’ book series, the film *Spider-Man 2*, the television series *Earth: Final Conflict* and a wealth of computer and video games are examples of pulp fiction featuring implants or brain implants.

The Gap Cycle (The Gap into): Some of the storylines in the book series written by Stephen R. Donaldson revolve around the use of technology known as ‘zone implants’, both appropriate and inappropriate.

In the anime and manga series *Ghost in the Shell*, the Cyberbrain’s neural augmentation technology plays a significant role. A substantially expanded memory capacity, complete recall and the ability to examine one’s own memories on an external viewing device are all benefits that can be achieved through the implantation of sophisticated computers into the body. Users also have the ability to initiate telepathic communication with other Cyberbrain users; however, the risks associated with this function include Cyberbrain hacking, malicious memory alterations and the deliberate manipulation of subjective reality and experience.

In the novel *Oath of Fealty* (1981) by Larry Niven and Jerry Pournelle, a private company responds to unrest in the Los Angeles area by constructing an arcology housing a society resembling feudalism and characterised by a high degree of surveillance. Some high-ranking executives are able to connect directly to MILLIE, the sophisticated computer system that runs its operations, and, through expensive implants placed in their brains, gain omniscience regarding the workings of the arcology. MILLIE is responsible for operating the system.

A new technology capable of capturing and transmitting thoughts, feelings and sensations is the subject of the 1983 film *Brainstorm*, in which the military seeks to gain control of the technology.

The film *RoboCop* (1987) combines elements of science fiction and action. Alex Murphy, a police officer, is killed but is later revived as a cyborg law enforcement officer with superhuman abilities.

Johnny Mnemonic (1995): The main character acts as a ‘mnemonic courier’ by using a memory implant in his

brain, which enables him to transport sensitive information between parties without being detected.

In the 2004 film *The Manchurian Candidate*, the protagonist, Raymond Shaw, is a presidential candidate who, unbeknownst to him, has had a chip secretly implanted in his brain by the fictional geopolitical organisation Manchurian Global. This chip is a form of mind control used by Manchurian Global to turn government officials into sleeper agents or puppets for their own financial gain.

In the 2009 film *Hardwired*, the main character has a chip implanted in his brain by a company seeking to take its marketing to the next level.

Marcus Wright, a character in the 2009 film *Terminator Salvation*, discovers that he is a cyborg and must decide whether to fight on the side of humanity or an evil artificial intelligence.

1972: *The Confinement of Pleasure* A researcher in Germany attempts to tame excessively aggressive troops by developing implants that directly stimulate the pleasure centres of the

brain. This is part of an effort to find a solution. Also known as *The Mind Snatchers*. *The Man Who Made Six Million Dollars* (1974–1978)

Steve Austin accidentally injures himself and is later reconstructed as a cyborg

.

The Woman with the Bionic Limbs (1976–1978) After Jaime Sommers is involved in an accident, she is reconstructed as a cyborg.

After being convicted of murdering an officer of the repressive Federation, the character Olag Gan from Blake's 7 receives a brain implant designed to prevent him from exhibiting aggressive behaviour in future.

Dark Angel: The notorious Red Series are fitted with neuro-implants that are inserted into the brainstem at the base of the skull. These implants give them an adrenaline rush, increase their strength and make them almost invincible. Unfortunately, between six months and a year after receiving the implant, its effects kill them by exhausting their system.

The X-Files (Episode: 'Duane Barry', which is significant for the series' wider mythos): FBI agent Dana Scully discovers

discovers that she has an implant placed under the skin at the nape of her neck. This implant is capable of reading every thought and altering her memory through the use of electrical impulses that affect brain chemistry.

Brain implants are a common feature amongst members of the Borg Collective, as shown in the Star Trek series. These implants connect individuals to the overarching Borg collective consciousness.

Stargate SG-1 is a series that features advanced replicators and an alien race called the Asura, who communicate with humans by inserting their hand into their brains.

The Stargate SG-1 franchise refers to this as Stargate SG-1 (Series 7). Episode #705. It was to be titled ‘Revisions’. A computer network connected to the brains of all inhabitants. The artificial intelligence within the interface is capable of erasing and rewriting history, and it does so.

In the show ‘Fringe’, the Observers have an implant that looks like a needle and is self-guided. This implant gives them the ability to read minds and suppress the emotions of those around them.

Furthermore, the implant increases

the recipient’s IQ and enables teleportation over short distances.

Episode 81 or 13 of the fourth series of *Person of Interest*. One of the many innocent victims on whom Samaritan agents carry out experiments with brain implants, as depicted in the episode titled ‘M.I.A.’

Brain implants feature in various episodes of *The Outer Limits*. For example, in the episode “Straight and Narrow”, pupils are forced to have brain implants fitted and are subsequently controlled by them. A character named Jennifer Winter receives a brain implant in the film “The Message” so that she can hear better. In the episode “Living Hell”, a man named Ben Kohler undergoes the procedure to have a brain implant fitted so that he can continue to live. In the film “Judgment Day”, a chip is inserted into the medulla oblongata of a character’s lower brainstem when it is determined that the character is a criminal. The remote control, which is within range of the forcibly implanted chip, causes the recipient to experience immense torment and confusion. A woman with neurological difficulties receives a brain implant in

the episode ‘Awakening’, the tenth episode of the third series. This helps the woman to become more like a normal person. There are several episodes in the British science fiction anthology series *Black Mirror* in which the protagonists have implants in their heads, in their brains or in their eyes, which enable video recording and playback, augmented reality and communication.

In the first series of *Earth: Final Conflict*, episode 12 is titled ‘Sandoval’s Run’, and during this episode, the character Sandoval experiences a malfunction in his brain implant.

In the fourth series of *Earth: Final Conflict*, episode 12 is titled “The Summit”, and during this episode, the character Liam receives a brain-monitoring implant.

Players of the video games PlanetSide and Chrome have the option to use implants to enhance a variety of aspects of their gameplay, including their aim, speed and vision.

The Deus Ex video game series explores the nature and effects of human augmentation through the use of a wide range of prosthetics and brain implants. In the video game *Deus Ex: Human Revolution*, set in the year 2027, the impact that

human augmentation would have on society, as well as the controversy it can cause, is explored in detail. Some of the characters in the game have neurochips implanted in their brains to assist them in their jobs (or for their own amusement). One example is a hacker with a brain-computer interface that allows direct access to computer networks and also acts as a ‘human proxy’, enabling a person in a remote location to control their actions. Other examples include a helicopter pilot who has had chips implanted in her brain to help her control her aircraft more effectively and analyse flight paths, speed and spatial awareness; a CEO who receives an artificial arm to improve his baseball pitching ability; and a baseball player who receives an artificial arm.

The video game explores the downsides of this form of augmentation, as players who cannot afford the upgrades (or who do not agree to receive them) quickly find themselves at a significant disadvantage when competing against individuals whose abilities have been artificially enhanced. The alarming possibility of having to acquire mechanical or technological enhancements in order to secure employment

is also explored. The plot resolves the issue of implant rejection through the use of a fictional drug called ‘Neuropozyne’, which not only destroys glial tissue but is also highly addictive. As a result, people with augmentations have little choice but to continue purchasing the drug from a single biotech company that controls its price. People who do not take the drug may face rejection of their implants, leading to a loss of function, unbearable discomfort and even probable death.

In the computer game *AI: The Somnium Files*, a direct neural interface is used to invasively link the thoughts and dreams of two different people, to the point where one person can forcibly extract information from another person’s brain. This enables the possibility of telepathy. The significant concerns raised by this type of technology – such as the blurring of the minds of connected individuals, the trafficking of such individuals, and the forced, invasive interface – are addressed and form part of the central narrative. Despite the fact that the ethical implications are not

much, the core narrative focuses on the following:

{End of Chapter 1}

Chapter 2: Cyberware

The field of cyberware is one that remains largely unexplored (a proto-science, or rather a ‘proto-technology’). In the realm of science fiction, however, it is generally understood to refer to the hardware or mechanical components that are surgically implanted into a human body and serve as an interface between the human body’s central nervous system and the computers or other machines connected to it.

More formally:

Cyberware is a type of technology that aims to develop a functional connection between machines and computers and the human nervous system, which includes the brain.

Examples of potential cyberware encompass a wide range of applications, although the majority of recent research tends to approach the subject from one of two distinct perspectives: interfaces or prosthetics.

The first type attempts to establish a direct connection with the brain. In science fiction, the I/O port for the brain is often depicted as a data socket. It is the responsibility of this system to convert human thoughts into a language that a computer can understand, and to convert a computer's output into a language that humans can understand. Once developed, it will enable computers and humans to communicate directly with one another.

Most research in the field of direct brain-computer interfaces is carried out in laboratories at major universities. The experiments are often conducted on animals or slices of brain tissue obtained from donor brains, as this is considered more ethical. Most current research focuses on monitoring, recording and translating electrical impulses in order to better understand the countless electrical signals sent by the brain. The concept of a 'hands-free' mouse or keyboard is currently being researched and developed by various companies. This technology enables users to control various computer tasks by using their

brainwaves. These interfaces are sometimes also referred to as brain-machine interfaces (BMI).

More in-depth research focusing on whole-brain interfaces is currently being carried out, but is still at an early stage. Very few people are able to afford the enormous costs of such operations, and those who do often find the process tedious and a long way from their desired results. Research has progressed to the point where it is now possible to exercise a certain degree of control over a computer using only mental commands. A man who was paraplegic was able to write and check his emails after having a chip developed by Cyberkinetics in Massachusetts and BrainGate implanted in his brain.

The second type of cyberware is a more contemporary interpretation of prosthetics, which is a somewhat established medical speciality. The aim of modern prosthetics is to replicate the natural functions and appearance of the human body. Studies have been carried out in the sub-field of prosthetics and cyberware, which overlaps with these two areas. In these experiments, microprocessors capable of

control the movements of an artificial limb, are connected to the patient’s severed nerve endings. The patient is then trained to use the prosthesis, with the aim of eventually enabling them to move it in the same way as a normal limb.

{End of Chapter 2}

Chapter 3: Brain-Computer Interface

A brain-computer interface (BCI), often referred to as a brain-machine interface (BMI), is a direct communication link between the brain's electrical activity and an external device, most commonly a computer or a robotic limb. BCIs are frequently used for the purpose of researching, mapping, assisting, enhancing or restoring human cognitive or sensorimotor abilities. The term 'brain-computer interface' first entered the canon of scientific research in 1973 in Vidal's study.

Due to the brain's capacity for cortical plasticity, signals from implanted prostheses can, following an adaptation phase, be processed by the brain in the same way as those from natural sensory or effector channels. After many years of animal testing, the first neuroprosthetic devices to be implanted in humans did not become available until the mid-1990s.

Recent research in human-computer interaction has made great strides in identifying mental states

, thanks to the use of machine learning to analyse statistical temporal patterns derived from the frontal lobe (EEG brainwave data) (Relaxed, Neutral, Concentrating). Beginning with Hans Berger's discovery of the electrical activity of the human brain and the subsequent development of electroencephalography (EEG), the history of brain-computer interfaces (BCIs) can be summarised as follows: (EEG).

Berger was the first to measure human brain activity using EEG in 1924. By analysing EEG tracings, Berger was able to identify oscillatory activity, such as the Berger wave or the alpha wave, which has a frequency range of 8–13 Hz.

The very first recording device Berger used was fairly simple. He worked on his patients by inserting silver wires under their scalps. After some time, these were replaced with silver foils, which were wrapped around the patient's head with rubber bandages. Unfortunately, Berger found that when these sensors were connected to a Lippmann capillary electrometer, the readings were inaccurate. However, the use of more advanced measuring instruments, such as the Siemens double-coil recording galvanometer, which could

voltages as low as one ten-thousandth of a volt, was, however, essential for achieving the desired results.

Berger investigated the correlations between the changes in the EEG waveform diagrams he produced and various brain disorders. EEGs opened up entirely new avenues for researching the functioning of the human brain.

Music for Solo Performer (1965), written by the American composer Alvin Lucier, is regarded as one of the first examples of a brain-machine interface in operation. At that time, however, the term ‘brain-machine interface’ had not yet been coined. To trigger acoustic percussion instruments, the work utilises electroencephalography (EEG) as well as analogue signal processing equipment (filters, amplifiers and a mixing desk). To perform the piece, one must generate alpha waves and ‘play’ the various percussion instruments using loudspeakers situated either near or directly on the instruments themselves. This is achieved by acoustic means.

Following his initial contributions, Vidal did not participate in BCI research for several years, nor did he take part in BCI-related activities

such as conferences. In 2011, however, he presented the first BCI during a lecture funded by the Future BNCI Initiative, which took place in Graz, Austria. The presentation was met with a standing ovation from the audience. Alongside Vidal was his wife, Laryce Vidal, who had previously collaborated with him on his first BCI project when they were both students at UCLA.

A study on the non-invasive use of EEG to control a physical object – namely, a robot – was presented in 1988. The experiment described used EEG to control numerous starts, stops and restarts of the robot's movement along a path arbitrarily defined by a line drawn on the floor. The robot's default behaviour was to follow a line, utilising the robot's autonomous intelligence as well as its autonomous power source. In the context of the S1-S2-CNV paradigm, the experiment demonstrated how the brain's anticipatory state, as reflected by CNV, regulates the S2 summing unit in a feedback loop.

Electroexpectogram is the term given to the acquired cognitive waveform that represents learning about

expectations in the brain (EXG). Vidal included the CNV brain potential as one of the challenges for BCI in the article he published in 1973.

Studies carried out in the 2010s showed that brain stimulation might have the potential to restore functional connectivity and related behaviours by manipulating molecular processes of synaptic efficacy. This paved the way for the idea that, in addition to restoring function, BCI technology would also be capable of providing functionality.

Through its BRAIN programme, which began in 2013, DARPA has provided funding for BCI technology. Among other things, this funding has supported research at the University of Pittsburgh Medical Centre.

Neuroprosthetics is a subfield of neuroscience that focuses on the use of artificial devices, sometimes known as neural prostheses, to replace the function of damaged nervous systems and address brain disorders, as well as the function of sensory organs or organs themselves (such as the bladder or diaphragm). By December 2010, over 220,000 people worldwide had received cochlear implants as

neuroprosthetic devices. There are also a number of neuroprosthetic devices, such as retinal implants, which aim to restore a person’s vision. However, the pacemaker was the very first neuroprosthetic device ever developed.

In common parlance, the terms are often used interchangeably. Both neuroprosthetics and brain-computer interfaces (BCIs) work towards the same overarching goals, which include the restoration of sight, hearing, mobility, the ability to communicate and even cognitive function. Both make use of conventional scientific methods and surgical procedures.

Several research institutions have successfully recorded signals from the cerebral cortices of monkeys and rats to control BCIs and induce movement. It has been demonstrated that monkeys are able to manipulate computer cursors on a screen and command robotic arms to perform basic tasks simply by thinking about the task at hand and receiving visual input, without any physical activity. In the past,

BCI technology, such as the Stentrode developed by Synchron, has also been tested on sheep.

In 2020, Elon Musk's Neuralink successfully implanted a device into a pig. The device was developed by Neuralink. It was not until 1969 that Fetz and his colleagues at the Regional

Primate Research Centre and the Department of Physiology and Researchers at the University of Washington School of Medicine in Seattle have demonstrated for the first time that monkeys can learn to control the movement of a biofeedback-measuring arm using neural activity. These studies were carried out using the operant conditioning method. By recording neural ensembles (groups of neurons), many research teams have succeeded in capturing complex signals from the brain's motor cortex. These recordings were used to control external devices.

By surgically implanting neurotrophic cone electrodes in monkeys, Phillip Kennedy and his colleagues were able to create the first intracortical brain-computer interface. Kennedy founded Neural Signals in 1987.

In 1999, researchers at the University of California, Berkeley, led by Yang Dan, succeeded in deciphering the neural

firings to replicate the visual stimuli seen by cats. The researchers used a grid of electrodes surgically implanted into the thalamus of cats with acute vision. The thalamus is the part of the brain responsible for integrating all sensory data. The researchers focused on 177 brain cells in the area of the thalamus known as the lateral geniculate nucleus, which is responsible for decoding information received from the retina. The cats watched a total of eight different short films whilst their neuronal firing patterns were monitored and recorded. The researchers were able to reconstruct recognised images and moving objects after decoding the signals using mathematical filters to create videos of what the cats were seeing. This allowed them to see what the animals were seeing. Since then, researchers in Japan have also achieved similar results in humans (see below).

Miguel Nicolelis, a professor at Duke University in Durham, North Carolina, is known to be a leading advocate of using multiple electrodes spread across a larger region of the brain to collect neural impulses

that can power a brain-computer interface (BCI).

Nicolelis and his colleagues developed BCIs that decoded brain activity in owl monkeys and used the devices to replicate the monkeys' movements in robotic arms, having first conducted studies on rats in the 1990s. These studies were carried out following earlier research on rats by Nicolelis and his colleagues. As monkeys have developed not only strong hand manipulation skills but also the ability to reach and grasp, they provide excellent test subjects for the work being carried out here.

By the year 2000, the team had achieved its goal of developing a BCI that successfully replicated the movements of an owl monkey as the monkey controlled a joystick or reached for food. The BCI operated in real time and was capable of remotely controlling a separate robot via the Internet Protocol. However, the monkeys could not see how the arm was moving, and they received no feedback; this type of BCI is known as an open-loop BCI.

In later tests, Nicolelis used rhesus macaques to successfully close the feedback loop, enabling him to replicate a monkey's grasping and reaching actions using a robotic arm. It is generally accepted that rhesus macaques are superior models for human neurophysiology than owl monkeys, thanks to their deeply fissured and convoluted brains. By moving a joystick, the monkeys were taught to reach for and grasp virtual objects displayed on a computer screen.

The corresponding movements of a robotic arm were concealed from the monkeys throughout the training.

The Carney Institute for Brain Science at Brown University, Andrew Schwartz's laboratory at the University of Pittsburgh and Richard Andersen's group at Caltech are some examples of other laboratories that have developed BCIs and algorithms for decoding neural signals. These researchers have successfully developed functional BCIs, even though they have recorded signals from far fewer neurons than Nicolelis (15–30 neurons as opposed to 50–200 neurons).

Rhesus macaques were trained in John Donoghue's laboratory at the Carney Institute to use a brain-computer interface (BCI)

to track visual targets displayed on a computer screen (a closed-loop BCI), with or without the use of a joystick.

In addition to predicting the kinematic and kinetic aspects of limb movements, brain-computer interfaces (BCIs) are now being developed that can predict the electromyographic or electrical activity of primate muscles. The electrical stimulation of muscles that such BCIs are capable of could be used to restore a certain degree of movement to paralysed limbs.

Research carried out by Miguel Nicolelis and his colleagues showed that the activity of large neural ensembles can accurately predict arm position. Based on this study, BCIs were developed that can interpret the user's intentions regarding arm movement and then translate these intentions into movements of artificial actuators. Carmena and her colleagues proposed that brain networks are restructured to generate a new representation of the robotic appendage in addition to the representation of the animal's own limbs. This new representation is generated alongside the representation of the animal's own limbs.

In 2019, researchers at the University of California, San Francisco (UCSF) presented a study in which they demonstrated a BCI that had the potential to help patients suffering from speech difficulties due to neurological disorders. Their brain-computer interface (BCI) utilised a patient's cerebral activity via high-density electrocorticography and synthesised speech using deep learning techniques.

The lack of a sensor modality that is safe, accurate and robust in accessing brain signals is currently the greatest challenge facing BCI (brain-computer interface) technology. Nevertheless, the creation of such a sensor within the next twenty years is something that can be envisaged and even considered feasible. It is expected that the use of such a sensor would significantly expand the scope of communication capabilities that a BCI can offer.

The development and implementation of a BCI system is a difficult and time-consuming process that presents significant challenges. To find a solution to this problem, Gerwin Schalk has been working on a system for BCI research that can be used for a variety of purposes, known as the BCI2000. Since 2000, the Brain-Computer

Interface Research and Development Programme at the Wadsworth Centre of the New York State Department of Health in Albany, New York, USA, has been overseeing the development of the BCI2000 system.

In vivo regulation of the activity of genetically defined subsets of neurons can now be achieved using a novel ‘wireless’ method that utilises light-controlled ion channels such as channelrhodopsin. Illuminating transfected cells in the somatosensory cortex affected the decision-making process of freely moving mice when the learning task was presented in a simple manner.

During human-computer interaction, passive BCIs, in addition to active and reactive BCIs used for directed control, enable the evaluation and interpretation of changes in the user’s state (HCI). The computer system learns from its user within an implicit secondary control loop, which generally makes the system more user-friendly.

In addition to decoding brain activity to drive external effectors, BCI systems can also be used to encode signals from the peripheral nervous system. These sensory BCI devices enable real-time judgements

that are relevant to a person’s behaviour, based on closed-loop brain stimulation.

The Brain-Computer Interface Research Foundation presents the Annual BCI Research Award in recognition of exceptional and groundbreaking work in the field of brain-computer interfaces. Each year, a renowned research institution is invited to act as the jury for the submitted proposals. The awarding laboratory was responsible for recruiting world-renowned BCI specialists to serve on the jury. The jury selects twelve candidates to be nominated and then chooses one winner for first place, one for second place and one for third place. These winners receive prizes of USD 3,000, USD 2,000 and USD 1,000 respectively.

The invasive form of BCI requires the surgical implantation of electrodes beneath the scalp to transmit brain signals. The main advantage is that it provides more accurate readings; on the other hand, some of the side effects of the procedure are unpleasant. Scar tissue may develop as a result of the operation, which can cause the brain impulses to become weaker. According to the findings of the study by Abdulkader et

al. (2015), the body may not be able to absorb the implanted electrodes, which can lead to a medical condition.

Researchers using invasive brain-computer interfaces have focused their efforts on restoring impaired vision and developing novel applications for patients who are paralysed. During neurosurgery, invasive brain-computer interfaces are surgically implanted into the patient's grey matter. As they are implanted in grey matter, invasive devices produce the highest-quality signals of all BCI devices. However, they are susceptible to the build-up of scar tissue, which can weaken the signal or even cause it to disappear altogether. This is because the body reacts to a foreign body in the brain by producing scar tissue.

In the field of vision research, direct brain implants have been used as a method of treating acquired (as opposed to congenital) blindness. William Dobelle, a researcher in the commercial sector, was one of the pioneering scientists who developed a brain interface capable of successfully restoring vision.

In 1978, Dobelle's first prototype was surgically implanted in 'Jerry', an adult man who had been born blind. Jerry's visual cortex was implanted with a single-array brain-computer interface (BCI) comprising 68 electrodes. This proved successful in generating phosphene, which is the sensation of seeing light. To transmit signals to the implant, the device used cameras mounted on a pair of glasses. At first, Jerry could only see different shades of grey with a limited field of vision and a slow frame rate because of the implant. To do this, he also had to be connected to a mainframe computer; however, as electronics have become smaller and computers faster, his artificial eye has become more portable, and he is now able to carry out basic activities without the help of another person.

One of the early examples of the use of BCIs in a commercial setting was in 2002, when Jens Naumann, who had also lost his sight as an adult, became the first of 16 paying patients to receive Dobelle's second-generation implant. This was one of the earliest commercial applications of BCIs. The second iteration of the device used an implant

which was technically more advanced, enabling improved mapping of phosphenes into coherent vision. In the phenomenon that researchers refer to as the ‘starry night effect’, phosphenes appear to be distributed across the visual field.

Almost immediately after receiving the implant, Jens was able to use his partially restored vision to drive a car cautiously around the research centre’s car park.

BCIs focusing on motor neuroprosthetics aim either to restore mobility to people who are paralysed or to provide devices to assist them, such as computer interfaces or robotic arms.

Researchers at Emory University in Atlanta, Georgia, led by Philip Kennedy and Roy Bakay, were the first to successfully implant a brain-computer interface in a person that generated signals of sufficient quality to mimic movement. Following a brainstem stroke in 1997, their patient Johnny Ray (1944–2002) was diagnosed with locked-in syndrome and died in 2002. Ray’s implant was fitted in 1998, and he survived long enough to work with it and eventually learn how to control a computer cursor.

Ray died in 2002 from a brain aneurysm, but he was able to

death. A year later, Professor Jonathan Wolpaw received the Altran Foundation for Innovation Award for his work on developing a brain-computer interface that uses electrodes positioned on the surface of the skull rather than directly within the brain.

More recently, research teams led by the BrainGate group at Brown University have demonstrated further successes in the direct control of robotic prostheses with many degrees of freedom by establishing direct connections to arrays of neurons in the motor cortex of patients with tetraplegia. These studies were conducted in collaboration with the United States Department of Veterans Affairs.

A team from Stanford University published the results of a successful proof-of-concept trial in May 2021. The trial enabled a tetraplegic participant to type English phrases at a rate of approximately 86 characters per minute and 18 words per minute. The subject imagined moving his hand to form letters, and the system carried out handwriting recognition based on electrical signals recorded in the participant’s motor cortex.

hidden Markov models and recurrent neural networks were used.

Recording brain activity using invasive BCIs presents a variety of technological challenges. There are several such issues. Advances in CMOS technology are driving the development of integrated, invasive BCI designs that are smaller, consume less power and have greater signal acquisition capabilities.

In recent decades, one of the most active areas of research has been the development of electronic alternatives to invasive BCIs. Chronic invasive brain-computer interfaces rely on the recording of extracellular voltages, which are typically three orders of magnitude smaller than intracellular voltages, which are in the region of hundreds of microvolts. Intracellular recordings from neurons reveal action potential voltages on the scale of hundreds of millivolts, but chronic BCIs rely on the recording of extracellular voltages.

Devices considered to be minimally invasive are those that are implanted into the skull but do not actually rest within the brain’s grey matter. They generate signals with a higher resolution than non-invasive BCIs, which are hindered by the

skull’s bony structure, which deflects and distorts the signals, and they are less likely to cause scar tissue to form in the brain compared with fully invasive BCIs. There have been demonstrations in preclinical settings of intracortical BCIs originating from the perilesional cortex following a stroke.

The feasibility of endovascular brain-computer interfaces has been the subject of several clinical and non-clinical studies dating back decades, as discussed in a systematic review published in 2020. In 2010, researchers affiliated with the University of Melbourne began developing a BCI that could be implanted via the vascular system. The concept for this brain-computer interface (BCI), known as the ‘stentrode’ and funded by DARPA, was developed by the Australian neurologist Thomas Oxley, who works at Mount Sinai Hospital. Evaluations of the technology were carried out as part of preclinical research on sheep.

The Stentrode is a monolithic stent-electrode array designed to be delivered to the superior sagittal sinus using an intravenous catheter, whilst guided by imaging

technology. This area is located adjacent to the motor cortex. The procedure eliminated the need for open-brain surgery and marked the first time a brain-computer interface had been implanted via the patient's blood vessels.

Electrocorticography, also known as ECoG, is a non-invasive method for measuring the brain's electrical activity, carried out in a manner comparable to non-invasive electroencephalography, with the exception that the electrodes used in ECoG are embedded in a thin plastic pad positioned over the cortex and beneath the dura mater.

Subdural or epidural signal transmission is possible; however, these signals do not originate from the brain parenchyma itself. As so few participants are available, serious research into this topic has only recently begun. At present, the only way to obtain the signal for study is to use patients who require invasive monitoring for the purpose of identifying and excising epileptogenic foci.

As it offers higher spatial resolution, a better signal-to-noise ratio, a broader frequency range and fewer training requirements than scalp-recorded EEG, ECoG is a highly promising intermediate BCI modality. At the same time, it presents fewer technical challenges, carries a lower clinical risk and may offer superior long-term stability compared to intracortical single-neuron recording. These are all reasons why ECoG is a better option than intracortical single-neuron recording, given that light-responsive brain-computer interface devices are still merely a hypothesis at this stage.

Edward Chang and Joseph Makin of the University of California, San Francisco, conducted recently published research and found that ECoG signals could be used to decode speech from epileptic patients who had high-density ECoG arrays implanted over the peri-sylvian cortices. By using a neural encoder-decoder network that converted ECoG data into one of fifty phrases comprising 250 different words, the authors of this study achieved word error rates of

3 per cent, representing a significant improvement over previous studies.

Experiments have also been conducted on humans using neuroimaging technologies that do not involve invasive procedures as interfaces. The vast majority of work carried out and published on BCIs involves non-invasive EEG-based BCIs. The use of non-invasive EEG-based technologies and interfaces has expanded significantly in recent years and now encompasses a broad spectrum of different fields of application. Despite the fact that EEG-based interfaces are easy to wear and do not require surgery, they have relatively poor spatial resolution and are unable to utilise higher-frequency signals effectively.

This is because the skull attenuates signals, which in turn scatters and blurs the electromagnetic waves generated by the neurons. EEG-based interfaces require some time and effort before each session, whereas non-EEG-based and intrusive interfaces do not require any training prior to use. Generally speaking, the ideal BCI for any individual depends on a variety of parameters.

Electrooculographic (EOG) signals were used in a study presented in 1989 on the topic of controlling a mobile robot via eye movement. Five EOG commands, interpreted as forward, backward, left, right and stop, were used to guide a mobile robot from its starting point to its destination.

An article published in 2016 describes a completely new communication device and a non-EEG-based human-computer interface. The device does not require visual fixation and does not require the user to be able to move their eyes in any way. The user interface is based on the concept of covert attention, whereby attention is directed towards a specific letter on a virtual keyboard without the user having to move their eyes to look directly at the letter. Each letter has its own unique circle, which serves as a background and fluctuates in brightness in a manner distinct from that of the other letters. The selection of the letter is determined by identifying the pattern of random fluctuations in pupil size that most closely matches the fluctuation pattern of the brightness of the background circle

. Furthermore, the user's mental rehearsal of the words 'light' and 'dark', in synchronisation with the changes in brightness of the letter circle, helps to improve the system's accuracy.

Between 2014 and 2017, a brain-computer interface (BCI) utilising functional near-infrared spectroscopy was able to give 'locked-in' individuals suffering from amyotrophic lateral sclerosis (ALS) the ability to communicate with others at a basic level.

Early reports on this non-invasive approach included the control of a 2D cursor using VEP (Vidal 1977), the control of a buzzer using CNV (Bozinovska et al. 1988, 1990), the control of a physical object – a robot – using a brain rhythm (alpha) (Bozinovski et al. 1988), and the control of text being written on a screen using P300. The BCI challenge was first set by Vidal in 1973. (Farwell and Donchin, 1988). (Birbaumer had previously trained people with epilepsy to control this low-voltage pulse in order to avert impending seizures.) In the experiment, 10 patients were taught to control the movement of a computer cursor by adjusting the frequency of their

brain waves. The process was laborious; patients took more than an hour to type 100 letters using the cursor, and training often lasted several months.

On the other hand, the slow cortical potential method for brain-computer interfaces (BCIs) has not been used for some time, as alternative methods require little or no training, are faster and more accurate, and are applicable to a larger proportion of users.

The type of oscillatory activity detected is another factor taken into account in the study. Gert Pfurtscheller founded the BCI Lab in 1991 and incorporated the findings of his research into motor imaging into the world's first online BCI, which was based on oscillatory features and classifiers. Together with Birbaumer and Jonathan Wolpaw from the State University of New York, they focused on developing technologies that would enable users to select the brain signals they found easiest to use for operating a BCI. These brain signals include mu and beta rhythms.

Another factor to consider is the type of feedback system used, which can be seen in research on P300

signals. Patterns of P300 waves are generated involuntarily (stimulus-feedback) when individuals see something they recognise. These patterns can enable brain-computer interfaces to decipher categories of thought without patients first needing to be trained. In contrast, the biofeedback techniques discussed above require the individual to learn how to manipulate their brainwaves in order to observe the resulting activity in their brain.

Research into EEG emulation of digital control circuits for BCIs was carried out in 2005, providing an example of a CNV flip-flop. Bin He and his colleagues demonstrated the ability of a non-invasive EEG-based brain-computer interface to control the flight of a virtual helicopter in three-dimensional space based on motor imagery. This capability was refined through an approach that incorporated both neuroimaging and a training protocol.

At the University of California, Davis, Babak Taheri produced the first single- and multi-channel dry active electrode arrays using microfabrication in the early 1990s. In

1994, both the construction of a single-channel dry EEG electrode and the results of its use were published. It was demonstrated that the arrayed electrode performed well compared to silver and silver chloride electrodes. [Citation needed] The device had four different sensor positions, each of which featured integrated electronics to reduce noise through impedance matching. These types of electrodes offer a number of advantages, including (1) no need for any kind of electrolyte, (2) no skin preparation required, (3) a significant reduction in sensor size, and (4) compatibility with EEG monitoring systems. The active electrode array is an integrated system comprising a series of capacitive sensors with local integrated circuits, housed in a casing containing batteries to power the electronics.

This integration was essential for the electrode to achieve the desired level of functional performance.

The electrode was evaluated using four different types of EEG activity, including (1) spontaneous EEG, (2) sensory event-related potentials, (3) brainstem potentials and (4) cognitive event-related potentials, utilising both an

an electrical test bench and human volunteers. Compared with the performance of typical wet electrodes, the dry electrode proved superior in several respects, including skin preparation, the absence of a need for gel (dry) and a higher signal-to-noise ratio.

It is believed that the NCTU brain-computer interface headband was developed in 2009. In addition to developing this BCI headband, the researchers also developed dry electrodes for silicon-based microelectromechanical systems (MEMS) with the intention of applying them to hairless areas of the body. Snap-on electrode holders were used to attach these electrodes to the data acquisition board housed within the headband. The patients' alertness and cognitive function were assessed using a Bluetooth-enabled telephone, whilst alpha activity was monitored by the signal processing module. The telephone would send stimulating feedback to the operator if the subject became drowsy, so that they would wake up and remain alert. This study was made possible by funding from the National Science Council of Taiwan, the

Republic of China (NSC), National Chiao Tung University, the Ministry of Education in Taiwan and the United States Army Research Laboratory.

In 2011, the researchers noted that ongoing work should focus on user-friendliness, performance robustness and reducing the cost of hardware and software. The technology needed to be evaluated during operation.

In 2013, researchers conducted experiments using mobile EEG-based brain-computer interface technology. They measured SSVEPs from individuals whilst they were walking on a treadmill at different speeds. These studies were made possible thanks to funding from the Office of Naval Research, the Army Research Office and the United States Army Research Laboratory. According to the data presented, the detectability of SSVEPs using CCA decreased as speed increased. As independent component analysis (ICA) has proven effective in isolating EEG data from noise, this method is used. Non-invasive brain-computer interfaces have also been used to enable patients with paralysis to operate upper and lower limb prosthetic devices using their brain activity. For example,

Gert Pfurtscheller of Graz University of Technology and his colleagues developed a BCI-controlled functional electrical stimulation system to restore upper limb movement in a person who had tetraplegia as a result of a spinal cord injury. In 2009, Alex Blainey, an independent researcher based in the UK, was able to effectively operate a five-axis robotic arm using the Emotiv EPOC. He subsequently designed several mind-controlled wheelchairs and home automation systems that could be operated by people with little or no motor control, such as those with spinal cord injury and cerebral palsy. These inventions were able to be used by people with disabilities.

Since the 1970s, DARPA has been supporting ongoing research into the potential military applications of brain-computer interfaces (BCIs).

In 2001, a collective of DIY neuroscientists and technologists launched a project called The OpenEEG Project. The ModularEEG was the main device developed by the OpenEEG community. It was a 6-channel signal acquisition board that could be built at home for between 200 and

400 US dollars. The OpenEEG Project marked a significant turning point in the development of DIY brain-computer interfaces.

‘How to Hack Toy EEGs’ was a comprehensive guide published in 2010 by the Frontier Nerds of NYU’s Information Technology Programme (ITP). This guide described how to build a single-channel EEG at home using an Arduino and a Mattel Mindflex, at a very affordable price. It sparked the interest of many people who were just starting out in the world of DIY brain-computer interfaces. This guide made a significant contribution to the DIY BCI movement.

In 2013, a DARPA call for proposals led to the founding of OpenBCI, which was subsequently funded through a Kickstarter campaign. They produced a low-cost, open-source 8-channel EEG acquisition board and marketed it under the brand name ‘32bit Board’. The retail price of the board was less than 500 US dollars. Two years later, they developed the first 3D-printed EEG headset, which they called Ultracortex. They also developed a 4-channel EEG acquisition board,

which they called the Ganglion Board, and they priced it at less than a hundred dollars.

Both magnetoencephalography (MEG) and functional magnetic resonance imaging (fMRI) have proven to be effective non-invasive brain-computer interfaces (BCIs).

The practice of motor imagery involves visualising the movement of various parts of the body. This mental exercise activates the sensorimotor cortex, which in turn regulates sensorimotor oscillations in the electroencephalogram (EEG). The BCI can detect this to determine the user's intention. Before satisfactory control of the BCI via motor imagery can be achieved, the patient will likely need to undergo numerous training sessions.

Before users are able to use the approach regularly with acceptable accuracy, they may need to attend these training sessions for a number of hours spread over many days. Despite the duration of the training sessions, users are unable to familiarise themselves with the control scheme. For this reason, the overall pace of gameplay tends to be rather sluggish.

The degree of mental relaxation in a subject can be monitored using biofeedback. In other cases, electroencephalography (EEG) is not the type of parameter monitored by biofeedback. Rather, electromyography (EMG), galvanic skin response (GSR) and heart rate variability (HRV) are some of the physiological parameters that are measured (HRV). Various types of biofeedback systems are used in the treatment of a wide range of conditions, including attention deficit hyperactivity disorder (ADHD), sleep problems in children, teeth grinding and chronic pain. EEG biofeedback systems often require the patient to exert control over four different frequency bands (theta: 4–7 Hz, alpha: 8–12 Hz, SMR: 12–15 Hz and beta: 15–18 Hz), which are monitored by the device. The passive brain-computer interface (BCI) is a type of BCI used to enrich human–machine interaction with implicit information about the user's actual state. For example, simulations can be used to detect when users intend to press the brake during an emergency braking manoeuvre when passive BCIs

are in use. Video game developers who utilise passive brain-computer interfaces (BCIs) must be aware that the user's cognitive state shifts or adapts as players progress through different levels of the game. During the first playthrough of a level, the user reacts to different things than during the second playthrough of that level. For example, the user will be less startled by an in-game event if they are expecting it and are prepared for it.

A visually evoked potential, or VEP, is an electrical potential measured when a participant is shown a type of visual stimulus. There are various types of VEPs.

Steady-state visual evoked potentials (SSVEPs) utilise potentials generated by stimulating the retina with visual stimuli modulated at specific frequencies. These potentials are used to measure brain activity. The patterns used to generate the stimuli for the SSVEP often take the form of alternating chequerboard patterns, although they sometimes consist simply of flashing images. The frequency of phase reversal of the stimulus used can be easily identified in the

easily identified within the EEG spectrum; this allows SSVEP stimuli to be identified with reasonable ease. SSVEP has proven effective within a wide range of BCI systems. This is due to a number of reasons, including the fact that the generated signal is observable in as large a population as that for transient VEP and blink potentials, and the fact that electrocardiographic artefacts do not affect the frequencies under investigation. The topographical organisation of the primary visual cortex is such that a larger area receives afferents from the centre or foveal region of the visual field.

This contributes to the exceptionally robust nature of the SSVEP signal. Nevertheless, SSVEP suffers from a number of problems. As SSVEPs infer a user's intention based on flashing stimuli, the user must fix their gaze on one of the flashing or iterating symbols in order to interact with the system. For this reason, the symbols may become tedious and difficult to use during prolonged gaming sessions, which can often last longer than an hour – a duration that may not be appropriate for gaming.

The P300 potential is an additional type of VEP used in applications. The event-related P300 potential is a positive peak in the EEG that occurs approximately 300 milliseconds after the presentation of a target stimulus (a stimulus the user is expecting or seeking) or oddball stimuli. This peak occurs because the brain is preparing for the target stimulus or the odd stimuli. The amplitude of the P300 wave decreases as the ignored stimuli and the target stimuli become more similar. It is believed that the P300 is associated with a higher level of attentional processing or an orienting response. The use of the P300 as a control method has the advantage that the participant only needs to attend a minimal number of training sessions. The P300 matrix was the very first application to use the P300 computational model. A participant using this method would select a letter from a grid in which numbers and letters are arranged in a 6 × 6 grid. The rows and columns of the grid would flash in a sequential pattern, and the user's P300 would (potentially) be triggered every time the user's 'selected letter' was illuminated on the grid display. On the other hand, the

communication rate was somewhat sluggish, at around 17 characters per minute. The P300 is a brain-computer interface (BCI) that provides users with a discrete selection mechanism rather than a continuous control mechanism. Players do not need to teach themselves how to use a completely new control system and therefore only need to undergo brief training sessions to learn the game mechanics and the basic use of the BCI paradigm when the P300 is used in games. This is one of the advantages of using the P300.

Gerwin Schalk discovered that ECoG signals can distinguish between the vowels and consonants embedded in spoken and imagined words. This discovery shed light on the different mechanisms associated with the production of vowels and consonants and could form the basis for brain-based communication using imagined speech. The initiative to develop devices for telepathic communication was funded by the United States Army with US$6.3 million. Schalk received a grant of US$2.2 million to support his research.

Using non-invasive devices that made contact with the participants' scalps, another group of researchers was able to establish conscious brain-to-brain communication between two people who were physically separated from one another. The hypothetical motor input from the person 'transmitting' the information was used to encode the words into binary streams consisting of sequences of ones and zeros. As a result of this experiment, supposedly random bits of information carried encoded versions of the words 'hola' (meaning 'hi' in Spanish) and 'ciao' (meaning 'goodbye' in Italian). These words were then transmitted from mind to mind between people who were physically separated from one another and whose motor and sensory systems had been blocked. The probability of this happening by chance was extremely low to non-existent. [1]

At the University of California, Irvine, a team led by scientist Mike D'Zmura is attempting to create synthetic telepathy through the use of subvocalisation in their research. The first transmission of this kind took place in the 1960s using EEG, whereby the brain's alpha waves were converted into Morse code. The electroencephalogram

(EEG) is a less precise technique for communicating imaginary speech than the more invasive approach of placing an electrode between the skull and the brain.

Thanks to the gadgets developed by the researchers, it is now possible to interact with brain cells and entire neural networks grown in cultures outside living animals.

Experiments on cultured nerve tissue have focused on building problem-solving networks, constructing basic computers and manipulating robotic devices, as well as advancing research into implantable devices for animals.

This research has also been used to further investigate implantable devices for animals. Research into methods for stimulating and recording individual neurons grown on semiconductor chips is often referred to as neuroelectronics or neurochips. This field of research focuses on ways to stimulate and record individual neurons.

In 1997, a team from Caltech led by Jerome Pine and Michael Maher claimed to have developed the world’s first neurochip that actually worked. The device developed by Caltech can accommodate sixteen neurons.

At the University of Southern California, a group of researchers led by Theodore Berger began developing a neurochip in 2003 with the aim of creating an artificial or prosthetic hippocampus. The neurochip, intended as a prototype for the subsequent production of prostheses with higher brain functions, was designed to function in the brains of rats. The hippocampus was chosen as the target because it is often regarded as the region of the brain exhibiting the highest degree of organisation and structure. The purpose of this structure is to encode events into long-term memory for storage in other parts of the brain. After being removed from the cortex, the neurons were cultured in a Petri dish, where they immediately re-established connections with one another, creating a living neural network. The cells were arranged in a pattern across a grid comprising sixty electrodes, and they were used to control the simulator's pitch and yaw functions. The aim of the research was to gain an understanding of how computational tasks are performed and learnt by the human brain at the cellular level.

Adrian Stoica, a Caltech-affiliated researcher at JPL, presented the concept of ‘multi-brain aggregation’ at Humanity+ @Caltech in December 2010. Stoica refers to the idea of merging or integrating the brain signals of numerous individuals as ‘multi-brain aggregation’.

Sources:

It remains largely unclear what the long-term consequences for the user will be.

Obtaining informed consent from those who have difficulty speaking.

The impact of BCI technology on the quality of life of patients and their families, as well as on the lives of others around them.

Adverse health effects (e.g. it has been reported that neurofeedback involving sensorimotor rhythm training affects sleep quality).

Medical applications and the risks associated with their use.

Safety risks

The inability of certain changes in the brain to be translated into other forms

Claims that the influence of BCIs overrides free will and control over sensorimotor actions Claims that cognitive intent was inaccurately translated due to a BCI malfunction Issues relating to accountability and responsibility Claims that the influence of BCIs overrides free will and control over sensorimotor actions.

Deep brain stimulation is responsible for bringing about certain personality changes.

Concerns centre on the possibility of one day becoming a ‘cyborg’, in which one’s own body would contain both living and mechanical components.

Identity issues arising from the question: What does it mean to be human?

An inability to distinguish between actions controlled by humans and those controlled by machines, as well as a blurring of the boundaries between human and machine.

The use of such technologies by government agencies in the form of more sophisticated interrogation methods.

The process of selective enhancement and social stratification.

Concerns regarding the ethical conduct of research involving animal testing

When moving from animal testing to human trials, a number of ethical questions arise.

Moral issues

Privacy and reading people's minds. Tracking and 'tagging' systems

Consciousness control.

Movement control. Emotion control

In their current forms, the vast majority of BCIs are light years away from the ethical concerns discussed previously. In terms of their intended use, they are functionally analogous to corrective treatments. In 2009, Clausen made the following statement regarding BCIs: "BCIs raise ethical questions, but they are conceptually comparable to those that bioethicists have

other areas of treatment.” He emphasised that people’s expectations regarding the effectiveness and value of BCIs have a significant influence on the ethical analysis, as well as on the way in which BCI researchers should engage with the media. Furthermore, uniform standards can be established to ensure that consent processes involving incapacitated patients are conducted in an ethically sound manner.

The current use of BCIs sets precedents in the medical field, as does their future development. Just as the development of medicines began as a means of compensating for deficits but is now used to improve concentration and reduce the need for sleep, it is possible that the role of BCIs will gradually shift from that of treatments to that of enhancements.

Recently, a number of companies have simplified their medical EEG technology to develop more affordable BCIs for use in research and entertainment applications. Toys such as the

NeuroSky and the Mattel MindFlex, for example, have achieved a degree of commercial success.

In 2006, Sony was granted a patent for a brain-computer interface device that would enable radio waves to influence impulses in the neural cortex.

Alongside the launch of the NeuroBoy video game in 2007, NeuroSky also introduced the world's first consumer-friendly EEG at an affordable price. Furthermore, this was the first major EEG gadget to utilise dry-sensor technology.

In 2008, OCZ Technology developed a gadget based primarily on electromyography and intended for use in video games.

Square Enix, the company that developed Final Fantasy, announced in 2008 that it would be collaborating with NeuroSky to produce a game called Judecca.

Mattel and NeuroSky collaborated in 2009 to develop a video game called Mindflex, in which players had to guide a ball through a series of obstacles by controlling their brain's electrical activity (EEG). It is by far the most popular consumer-based EEG device released to date.

In 2009, the Star Wars Force Trainer was unveiled, a video game developed by Uncle Milton Industries in collaboration with NeuroSky, designed to give players the impression that they possessed the Force.

2009 saw the debut of Emotiv's EPOC, a 14-channel electroencephalogram (EEG) that reads four mental states, thirteen conscious states, facial expressions and head movements. The EPOC is the first commercially available BCI to utilise dry-sensor technology, which can be lubricated with a saline solution to achieve a more reliable connection.

The Neurowear product, known as 'necomimi', was named one of the top innovations of 2011 by Time Magazine in November of that year. The company announced that it planned to launch a consumer version of the garment in spring 2012, and that it would consist of cat-like ears controlled by a brainwave scanner manufactured by NeuroSky.

They Shall Walk is a charity dedicated to building exoskeletons, also known as LIFESUITS, for people with spinal cord injuries and tetraplegia. In February 2014

They Shall Walk entered into a partnership with James W. Shakarji to develop a wireless brain-computer interface (BCI).

In 2016, an open-source BCI circuit that transmits brain signals to a smartphone's audio jack was built by a community of electronics enthusiasts, reducing the cost of entry-level BCIs to £20.

A development kit costing US$399 and containing an EEG headset with dry electrodes was made available by NextMind in 2020. The device can be tested using a number of demonstration programmes, or programmers can create their own use cases using the included software development kit.

A roadmap designed to assist the European Commission in its funding decisions for the new Horizon 2020 framework programme was drawn up by a consortium of twelve different European partners. The project, which was launched in November 2013 and supported by the European Commission, produced a roadmap in April of the following year.

For example, this study analysed the work carried out as part of

this project to better define brain-computer interfaces (BCIs) and their applications, examined current developments, explored ethical challenges and assessed possible avenues for future BCIs.

Other recently published articles have also explored possible future avenues for BCI use by new categories of users with disabilities (e.g. individuals suffering from a disorder of consciousness (DOC)). Individuals in a coma, a vegetative state (VS) or a minimally conscious state (MCS) are considered to be in this condition according to the medical definition. Recent research into BCIs aims to support people living with DOC in various ways. Identifying individuals who are capable of performing basic cognitive activities is one of the primary initial objectives, as this would naturally lead to a change in their diagnosis.

This means that some people who have been diagnosed with DOC may, in reality, be capable of taking in information and making important decisions about their lives (e.g. whether to seek treatment, where to live, and their views on end-of-life decisions).

Some people diagnosed with DOC pass away as a result of decisions made regarding end-of-life care. These decisions may be made by family members who genuinely believe this is in the patient's best interests. It would appear that there is a significant ethical responsibility to pursue this line of research to ensure that DOC patients have the opportunity to determine whether or not they wish to live, given the new possibility of enabling these patients to express their views on this matter.

Many different factors, such as a stroke or an injury, can cause a person to lose some of their mobility. Recent studies have shown that EEG-based brain-computer interfaces can be useful in supporting stroke patients with motor recovery and neurorehabilitation. These studies have been carried out in recent years. In this method, a BCI is used to assess the patient's motor activity whilst the patient either imagines the movements or attempts to perform the movements guided by the therapist. Two potential benefits can be gained from the use of the

BCI: (1) The BCI could alert both the patient and the therapist if it detects that a patient is not visualising a movement correctly (this is referred to as non-compliance). (2) The patient's ability to receive rewarding feedback, such as functional stimulation or the movement of a virtual avatar, also depends on the patient's precise motor imagery.

Until now, the electroencephalogram (EEG) has been the standard method for measuring a patient's motor imagery in BCIs for motor recovery. However, fMRI has also been used in research to investigate the many changes that occur in the brain of individuals whilst they are participating in BCI-based stroke rehabilitation training.

During neurosurgery, over 400,000 patients undergo brain mapping procedures every year. People who have epilepsy or tumours but find that medication does not help them sufficiently are often candidates for this operation. During this operation, electrodes are positioned on the surface of the brain so that the specific locations of various structures and functional regions can be determined. During neurosurgery, patients may be awake and

asked to perform certain activities, such as moving their fingers or repeating phrases. This is crucial so that surgeons can remove only the tissue that needs to be removed, whilst sparing other areas, such as

B. those that are essential for movement or speech. It is possible to cause irreversible damage to the brain by removing an excessive amount of tissue, whilst removing an insufficient amount of tissue may leave the underlying condition untreated, necessitating further neurosurgery. Consequently, there is an urgent need to develop better methods and technologies to create as accurate a map of the brain as possible.

Researchers specialising in BCI technology and clinicians have recently been working on a series of articles to investigate novel applications of BCI technology that could improve neurosurgical mapping. This study focuses a significant amount of attention on high gamma activity, which is difficult to identify using non-invasive methods. The findings have led to the development of improved techniques for identifying critical regions responsible for movement, speech and other processes. Recent

research on functional brain mapping was discussed in an article that also provides a summary of a related workshop.

Polymers and other flexible materials (such as silk) are used to manufacture flexible electronics. In principle, reducing tissue damage could extend the lifespan of BCIs that rely on flexible electrode-tissue interfaces.

The term ‘neural dust’ is used to describe millimetre-sized devices that function as wirelessly powered neural sensors. These devices were proposed in a paper published in 2011 by the University of California, Berkeley Wireless Research Centre. The paper described both the challenges and the outstanding advantages of creating a long-lasting wireless BCI. ‘Neural dust’ is a term used to refer to these devices.

{End of Chapter 3}

Chapter 4: BrainGate

Cyberkinetics is the company that developed and formerly owned the brain implant device known as BrainGate, which is currently being developed and tested in clinical settings, designed with the aim of helping those who have lost control of their limbs or other bodily functions, people suffering from amyotrophic lateral sclerosis (ALS), or those who have sustained a spinal cord injury.

The BrainGate technology and Cyberkinetics' associated assets are now owned by the privately held company BrainGate, Inc.

The sensor, which is surgically implanted into the patient's brain, analyses the patient's brain activity and translates the user's intentions into commands that can be executed by a computer.

The current version of the BrainGate system consists of a sensor that is surgically implanted into the patient's brain, as well as an external decoder device that can be connected to a prosthesis or other external device. The sensor takes the form of a microelectrode array, formerly

known as the Utah Array. It consists of a hundred electrodes, each no thicker than a human hair, designed to detect the electromagnetic signature left by neurons firing in specific regions of the brain, such as the region responsible for controlling arm movement. This activity is converted by the sensor into electrically charged signals, which are then transmitted to an external device where they are decoded using software. The decoder connects to an external device and is able to use the brain signals to operate that device. This device can be anything from a robotic arm or a computer cursor to a wheelchair. In its most basic form, BrainGate enables users to control physical objects in the real world using only the power of their thoughts.

In addition to analysing neural patterns in real time to transmit movements, the BrainGate array is also capable of recording electrical data for analysis at a later date. One potential application of this functionality is for a neurologist to analyse seizure patterns in an epileptic patient.

Researchers from the Department of Neuroscience at Brown University, in collaboration with the biotechnology company Cyberkinetics, Inc., were the first to develop the BrainGate system. Cyberkinetics later transferred device production to Blackrock Microsystems. Blackrock Microsystems is the current manufacturer of the sensors and data acquisition equipment.

In 2002, Kevin Warwick, Mark Gasson and Peter Kyberd conducted the first studies, which were claimed to involve the implantation of a microelectrode array in a single human participant. These experiments were described as the first of their kind. This process is not yet complete.

In May 2012, researchers from BrainGate presented a study showing that two people who had been paralysed several years earlier by a brainstem stroke were able to control robotic arms to grasp and manipulate objects. The study was published in *Nature*.

In 2009, the ‘BrainGate2 Neural Interface System’ underwent its first round of clinical trials.

{End of Chapter 4}

Chapter 5: Neuroprosthetics

The field of study known as neuroprosthetics, also referred to as neural prosthetics, is linked to the study of neurology and biomedical engineering and focuses on the manufacture of neural prostheses. In certain cases, it is contrasted with what is known as a brain-computer interface, which represents a connection between the brain and a computer rather than a device designed to replace lost biological functions.

Neural prostheses are a range of devices capable of replacing a motor, sensory or cognitive function that may have been impaired as a result of an accident or illness. These impairments may have arisen from the damage caused. Cochlear implants are a type of device that falls into this category. These devices replace the eardrum and stapes, which are responsible for carrying out certain functions, and also simulate the frequency analysis performed by the cochlea. An external device fitted with a microphone collects and analyses sound; the processed signal is

then transmitted to an implanted unit, which stimulates the auditory nerve using an array of microelectrodes. These devices aim to improve the overall quality of life for people with impairments by restoring damaged senses or enhancing them in some way.

These implanted devices are also frequently used in animal experiments as a tool to help neuroscientists gain a deeper understanding of the brain and how it functions. They are typically employed as a tool to gain a better understanding of the brain and its functioning. It is possible to conduct research on a patient without the device influencing the results by using electrodes that are surgically placed in the individual's brain to transmit electrical impulses, which can then be monitored remotely.

It would be possible to gain a better understanding of the relationship between a local population of neurons responsible for a specific function if the electrical impulses in the brain were examined and recorded with greater accuracy.

To minimise damage to the surrounding tissue, neural implants are made as tiny as possible. This is particularly important in the regions around the brain, the eyes and the cochlea. In most cases, these implants use wireless communication to interact with their corresponding prostheses. Furthermore, electricity is now supplied via wireless power transfer, which takes place in the body's dermis. As the tissue surrounding the implant is often highly sensitive to increases in temperature, the power output must be kept to a minimum to prevent damage to the surrounding tissue.

In 1957, a cochlear implant was successfully implanted in a human for the first time. Other significant advances include the implantation of a peripheral nerve bridge into the spinal cord of an adult rat in 1981, the first auditory brainstem implant in 1977, and the first motor prosthesis in 1961, which was used to treat foot drop in patients with haemiplegia. In 1988, the lumbar anterior root implant and functional electrical stimulation (FES) enabled a number of people with spinal cord injuries to stand up and walk again.

In the early stages of manufacturing electrodes for surgical implantation into the brain, one of the challenges was locating the electrodes correctly. This was initially achieved by inserting the electrodes using needles and then cutting the needles off at the required depth. More recent systems use probes with a higher degree of technological sophistication, such as those used in deep brain stimulation therapy to treat Parkinson's symptoms. The difficulty with both techniques is that, whilst the brain can move freely within the skull, the probe cannot. Even relatively minor collisions, such as a low-speed accident, have the potential to cause significant damage to the brain. Some researchers, such as Kensall Wise of the University of Michigan, have advocated for 'electrodes intended to be placed on the outside of the brain' to be anchored to the inside of the skull. This would enable the electrodes to measure electrical activity in the brain. However, tethering would not solve the problem with devices designed to be implanted deep within the brain, as is the case with deep brain stimulation (DBS), even if it were effective.

By stimulating neurons in the visual system with an electric current, a visual prosthesis can create the sensation of seeing an image. The image would be transmitted wirelessly from the camera to the implant, and the implant would then map the image via a grid of electrodes. Stimulation of these photoreceptor neurons in the retina leads to the formation of an image, and the arrangement of the electrodes must be capable of efficiently stimulating between 600 and 1,000 sites. Stimulation can also be carried out at any point along the path taken by the optical wave. Either the visual cortex or the optic nerve can be activated to produce an image; however, clinical trials have shown that retinal implants were the most effective option.

One component of a visual prosthesis system is an imaging system, either implanted or external, which is responsible for capturing and processing video. The external device provides data and power to the implant wirelessly via its connection to the implant. The implant uses the received power and data to convert the digital data into an analogue output, which is then transmitted to the nerve via microelectrodes.

The specialised neurons known as photoreceptors are responsible for converting photons into electrical signals. They form part of the retina, a multi-layered neural structure that lines the back of the eye and is approximately 200 micrometres thick. The processed signal is then transmitted to the brain via the optic nerve. If any part of this pathway is damaged, it can lead to blindness.

Damage to the optical system (cornea, aqueous humour, crystalline lens and vitreous humour) can lead to complete or partial loss of vision. Accidents and diseases are also possible causes of this condition.

Age-related macular degeneration (also known as AMD) and retinitis pigmentosa are the two most common forms of retinal degeneration which, as a result of the loss of photoreceptors (RP), can lead to blindness.

A device featuring a passive microphotodiode array comprising 3,500 components was tested in the first clinical trial of a retinal prosthesis intended for permanent implantation. The results of this experiment showed that a device consisting of an implanted electrical stimulator can restore a certain

degree of vision. Recent research in the field of visual cortex prostheses has focused on determining whether stimulation of the visual cortex of a non-human primate is effective or not. In this experiment, after undergoing the training and mapping processes, the monkey is able to perform the identical visual saccade task, regardless of whether it is stimulated by both light and electrical stimulation.

The needs and wishes of blind people who will benefit from the device should guide the development of the specifications for a high-resolution retinal prosthesis. Interactions with these individuals suggest that the primary functional requirements are the ability to move without using a white cane, the ability to recognise faces, and the ability to read.

Owing to the availability of this new technology, a number of researchers, including Karen Moxon of Drexel University, John Chapin of SUNY and Miguel Nicolelis of Duke University, have begun investigating the development of an advanced visual prosthesis. Other researchers have disagreed with the focus of their study

, stating that the basic research and the construction of the densely packed tiny wire were not sophisticated enough to justify further investigation.

(To record sound)

The three main types of auditory prostheses are known as cochlear implants (CIs), auditory brainstem implants (ABIs) and auditory midbrain implants (AMIs). To activate auditory neurons in the inferior colliculus, CI electrode arrays are implanted into the cochlea; ABI electrode arrays stimulate the cochlear nucleus complex in the lower brainstem; and AMIs stimulate auditory neurons in the cochlea.

Implantable cochlear devices have achieved great success in all three areas. Today, Advanced Bionics Corporation, Cochlear Corporation and Med-El Corporation are the main players in the market for cochlear implants.

Cochlear implants are an alternative to conventional hearing aids, which amplify sound and transmit it via the outer ear.

Instead, cochlear implants pick up sound, analyse it and then convert it into electrical energy, which is then sent to the auditory nerve.

Ambient sound is picked up by the CI system’s microphone and then sent to the processor

. The sound is digitised by the processor and then filtered into many different frequency bands. These frequency bands are then sent to the specific tonotopic region of the cochlea that corresponds roughly to these frequencies.

In 1957, the French researchers A. Djourno and C. Eyries, with the support of D. Kayser, published the first comprehensive report on the direct stimulation of the auditory nerve in a human patient. Djourno and Eyries were assisted in their study by D. Kayser. Around 80,000 young people worldwide have been fitted with various types of implants.

C. was the first to introduce the idea of integrating simultaneous electro-acoustic stimulation, abbreviated to EAS, to improve hearing.

by Ilberg and J.

Kiefer, from Frankfurt University Hospital, Germany, in 1999.

Speech synthesis refers to the process of sound generation. An electrode and a generator are the two main components that make up the SCS (Spinal Cord

Stimulator). As this overlap is substantial (but not

sufficient) to enable pain relief,

the technical aim of SCS for neuropathic pain is to mask the site of a patient's distress with a stimulation-induced tingling sensation known as 'paraesthesia'. The distribution of the paraesthesia is determined by the afferent nerves that are activated. Large dorsal column afferents that induce extensive paraesthesia extending caudally are those most readily recruited by a dorsal midline electrode near the pial surface of the spinal cord.

In the past, the electric eel was used as a form of electroconvulsive therapy for pain relief. Healers had developed specialised and comprehensive procedures to harness the eel's generative properties to treat a variety of pain conditions, including headaches, amongst other types of pain. It required a considerable degree of skill to administer the treatment to the target area for the appropriate duration, as the use of a living shock generator is rather unpleasant. (This includes keeping the fish alive for as long as possible.) The first targeted use of electricity was in the treatment of pain using electroanalgesia. In the eighteenth century

the majority of Western doctors provided their patients with electrotherapy generated by a portable generator. By the mid-1960s, however, three factors came together to ensure the continued success of electrostimulation.

The technology behind pacemakers, first developed in 1950, became widely available.

Melzack and Wall presented their gate-control hypothesis of pain, which states that the transmission of pain can be prevented by stimulating large afferent fibres.

This theory was based on the idea that large afferent fibres are involved in the processing of noxious stimuli.

Early doctors were interested in the idea of stimulating patients' nervous systems to alleviate their suffering. The design options for electrodes include the many

ways in which the electrode can be implanted, as well as its size, shape, arrangement, number of contacts and the configuration of these connections. Design options for pulse generators include the power source, the anatomical target site, the current or voltage source, the pulse frequency, the pulse width and the number of independent channels. A wide range of programming options is available (a four-contact electrode

offers 50 functional bipolar combinations). Modern technologies utilise computer-aided methods to determine which solutions are most beneficial to use. This reprogramming option adjusts the stimulation parameters to account for changes in posture, electrode migration, shifts in pain locations and sub-optimal electrode placement.

The bladder control implant is an example of a device that helps to maintain the functioning of the autonomic nervous system. Alongside the somatic nervous system, the lumbar anterior root stimulator and functional electrical stimulation work in tandem to support conscious control of movement.

Patients who have suffered a spinal cord injury resulting in paraplegia experience difficulties with bowel movements, which increases their risk of developing an infection. From 1969 onwards, Brindley worked on the development of the sacral anterior root stimulator, which was eventually tested on humans with great success from the early 1980s onwards. This device, which is implanted into the sacral anterior root ganglia of the spinal cord

, is controlled by an external transmitter and provides intermittent stimulation to improve bladder emptying. It also helps patients with defecation and gives men the ability to achieve a full erection that lasts for a longer period of time.

Sacral nerve stimulation, a similar technique, is used to treat incontinence in people who are physically able to undergo the operation.

Researchers are currently investigating and developing motor neuroprostheses to help people with motor disabilities, such as tetraplegia or amyotrophic lateral sclerosis, regain the ability to move and communicate with the outside world. These motor neuroprostheses help to restore movement and the ability to communicate with the outside world. Research has shown that the striatum is a key part of the brain involved in the acquisition of motor and sensory skills. This was established through an experiment in which the firing rates of the striatum were measured at higher levels after laboratory rats had performed a task repeatedly.

Researchers have developed microelectrode arrays that are smaller than one square centimetre and can be implanted into the skull to record electrical activity. The recorded information can then be transmitted via a thin cable. This enables scientists to record electrical signals from the brain. Neuroscientists were able to interpret the data sent by neurons as movements after studying monkeys for many decades. To complete this translation, researchers have designed interfaces that enable patients to move computer cursors, and are beginning to build robotic limbs and exoskeletons that patients can operate simply by thinking about movement. Patients will be able to use these devices.

The technology underpinning motor neuroprostheses is still at an early stage of development. Both the researchers and those involved in the study will continue to explore various applications of the prostheses. For example, instructing a patient to think about clenching a fist rather than instructing them to think about tapping a finger on a table

. Furthermore, the filters used in the prosthesis are undergoing a process of fine-tuning, and in the not-too-distant future, medical professionals expect to develop an implant capable of transmitting signals wirelessly from inside the skull, rather than via a cable.

Prior to these improvements, Philip Kennedy (Emory and Georgia Tech) had a device that was functional, albeit relatively simple, which enabled a paralysed person to spell out words by modulating their brain activity. The system developed by Kennedy used two neurotrophic electrodes. The first of these electrodes was placed in an undamaged area of the motor cortex (e.g. the finger representation area) and used to move a cursor between a series of letters. The second was placed in a separate motor zone and served as an indicator of which option was being considered.

Dr Todd Kuiken of Northwestern University and the Rehabilitation Institute of Chicago has discovered a mechanism that enables an amputee to operate motorised prostheses and restore sensory input. This process is known as targeted reinnervation.

In 2002, a multi-electrode array consisting of one hundred electrodes was surgically implanted directly into the median nerve fibres of a scientist named Kevin Warwick. This array currently serves as the sensor component of a ‘Braingate’. The recorded signals were used to drive a robotic arm designed by Warwick’s colleague, Peter Kyberd. This robotic arm was able to replicate the movements that Warwick’s own arm could perform.

A unique amputation paradigm has been developed by the MIT Biomechatronics Group. This paradigm enables organic muscles and myoelectric prostheses to interact neurally with a high degree of reliability. This new surgical paradigm, known as the Agonist-Antagonist Myoneural Interface (AMI), enables the user to feel and control their prosthesis as if it were an extension of their own body. Until now, users have had to make do with a prosthesis that was little more than an appendage. When the agonist muscle contracts, the antagonist muscle is stretched in a typical agonist-antagonist muscle pair (e.g. biceps and

triceps) and vice versa. This enables the user to know the position of their limb without having to look at it. When a typical amputation is performed, the agonist and antagonist muscles of a limb, such as the biceps and triceps, are severed from one another. This eliminates the ability to have a dynamic contraction-elongation mechanism responsible for generating sensory input. As a result, amputees who use prostheses have no way of perceiving the surrounding physical world. Furthermore, with the existing method of amputation surgery, which has been in use for more than 200 years, one third of patients have had to undergo revision surgery due to discomfort in their stumps.

An AMI consists of two muscles that once had a relationship similar to that of an agonist and an antagonist. These two muscles are mechanically connected to one another within the severed stump whilst the amputation procedure is being carried out.

Patients with muscle tissue that has undergone extreme atrophy or damage, or patients undergoing revision surgery on an amputated limb for reasons such as neuroma pain, bone spurs, etc., may

be candidates for the creation of AMIs using regenerated muscle flaps. AMIs can be created for this type of patient.

In order to develop a prosthesis that successfully mimics normal biological synaptic impulses, it is very important to have an accurate characterisation of the non-linear input/output (I/O) properties of the normally functioning tissue to be replaced.

Integrated circuits are designed to mimic typical biological signals once the I/O properties have been analytically determined. For the prosthesis to behave like normal tissue, it must modify the incoming signals in the same way as natural tissue. This is known as the signal processing process.

In order for implantable devices to be placed directly in the brain, they must be very small – roughly the size of a quarter. The Utah Array is an example of a micro-implantable electrode array.

[Example:].

Control units that are wireless and can be placed outside the skull should be smaller than a pager.

A battery’s capacity is determined by its power consumption. Power requirements decrease as the implanted circuits are optimised. Currently, implantable devices require their own on-board power sources. Surgery is required to replace the device once the battery has run out. The longer the battery life, the fewer surgical procedures are needed to replace the batteries. The technology currently used in electric toothbrushes is one approach that can be employed to recharge implant batteries without the need for surgery or wiring. These gadgets use inductive charging technology to recharge their batteries. The conversion of electromagnetic energy into electrical energy is another option, and this is precisely what radio-frequency identification (RFID) tags do.

As cognitive prostheses are implanted directly into the brain, ensuring that they are biocompatible is a critical challenge that must be overcome. For long-term implantation, the appropriate materials must be selected for the device’s casing, the substance used for the electrodes (e.g. iridium oxide) and the insulation around the electrodes

. In accordance with the standards: Implants for surgery: Active implantable medical devices, ISO 14708-3 (15 November 2008), Part 3: Implantable neurostimulators.

A virus or other substance capable of eliciting an immune response can be introduced into the brain if it is able to cross the blood-brain barrier. The brain’s immune system is independent of the immune system of the rest of the body and functions differently from it.

Consider the following questions: How does this influence the choice of materials? Is it possible that the brain has its own specific phages, which behave differently and have the potential to alter the biocompatibility of materials in other parts of the body?

Wireless transmission technology is now being developed to enable the continuous recording of neural signals from people going about their normal lives. This allows healthcare professionals to collect more data, increasing the likelihood that transient events, such as epileptic seizures, will be documented, and paving the way for improved diagnosis and treatment of brain disorders.

A technology has been developed at Stanford University that is both compact and lightweight and enables continuous recording of neurons in monkey brains. This technology also allows neuroscientists to conduct brain research outside the sterile confines of a laboratory.

It is essential that robust and secure data transmission methods are used when neural prostheses are connected to external systems. The fact that wireless brain implants can suffer from the same kind of cybersecurity vulnerabilities as any other type of information technology system has given rise to the term ‘neurosecurity’. A breach of neurosecurity can be regarded as a violation of a patient’s medical privacy.

The implantation of the device presents several challenges. Firstly, the relevant presynaptic inputs on the device must be linked to the corresponding postsynaptic inputs on the device. Secondly, it must be ensured that the device’s outputs are appropriately targeted at the tissue of interest. Thirdly, the brain must adapt to using the implant. Several studies on brain plasticity suggest the

possibility that this could be achieved through physical activities planned with the appropriate level of motivation.

Electrophysiological signals known as local field potentials (LFPs) are associated with the total amount of dendritic synaptic activity occurring within a specific volume of tissue. Recent research suggests that high-level cognitive processes, such as goals and expected value, can be utilised for neural cognitive prostheses. [Citation needed] [Citation needed] Furthermore, researchers at Rice University have developed a novel strategy for tuning the light-induced oscillations of nanoparticles by applying minute modifications to the surface to which the particles are attached. The university believes that the findings could pave the way for new applications of photonics in fields ranging from molecular sensing to wireless communication. They achieved this by exposing the atoms in gold nanosheets to ultra-fast laser pulses, which caused the atoms to oscillate.

The implantation of electrodes over a prolonged period is an obstacle that needs to be addressed. It is possible that

various nerves may be recorded by the electrodes if the electrodes shift due to a physical shock or because the brain moves relative to the electrode site. It is necessary to make adjustments to the electrodes in order to maintain an optimal signal. The process of individually tuning each multi-electrode array is both extremely laborious and time-consuming. The creation of electrodes that can automatically self-regulate would be a solution to this problem. Currently, the group led by Anderson is collaborating with the laboratory led by Yu-Chong Tai and the laboratory led by Burdick (both at Caltech) to develop such a system, which uses electrolysis-based actuators to adjust electrodes independently within an array of chronically implanted electrodes.

Image-guided surgery is used to precisely locate and implant devices in the brain.

{End of Chapter 5}

Chapter 6: Remote-Controlled Animals

Animals that are operated remotely by humans are referred to as ‘remote-controlled animals’. To perform certain tasks, it is necessary to surgically implant electrodes into an animal’s nervous system and then connect these electrodes to a receiver, which is often worn on the animal’s back. Radio signals are used to exert control over the animals. The electrodes do not move the animal directly, as if commanding a robot, but rather they communicate a direction or action desired by the human operator and then stimulate the animal’s reward centres when the animal responds to the signal. This is analogous to how a robot would be controlled. In certain circles, these are also referred to as biorobots or robo-animals. They can be classified as cyborgs, as they integrate electrical devices with biological life forms. Criticism has been levelled at the use of remote-controlled animals, particularly with regard to animal welfare and animal rights, due to the need to perform surgery on the animals and the moral and ethical dilemmas arising from their use. It has been claimed that a

comparable application, which does not require invasive surgery, can control an animal by stimulating its brain with ultrasound. Vibrations and sound are two methods used by some apps (most of which have been developed for dogs) to control the animals' behaviour.

It has been possible to exercise effective remote control over several different animal species. These include beetles, moths and other insects; animals controlled by remote control can be trained for specific tasks and deployed as working animals in a variety of contexts, including search and rescue missions.

Several studies have investigated the possibility of remotely controlling rats by implanting microelectrodes into their brains. These experiments rely on stimulating the rat's reward centre in order to be successful. A total of three electrodes are inserted into the rat's brain. Two of the electrodes are placed in the ventral posterolateral nucleus of the thalamus, which is responsible for transmitting sensory information from the left and right whiskers, and the third electrode is placed in the medial forebrain bundle, which is involved in the rat's reward process

. When the rat makes the correct choice between left or right, a pleasant electrical stimulation is sent to the brain via the third electrode. During training, the operator activates either the rat's left or right electrode. This causes the rat to 'feel' a touch on its whiskers corresponding to the stimulation, as if it had come into contact with an obstacle. If the rat displays the appropriate response at this point, the operator rewards the rat by activating the third electrode.

Concerns have been raised regarding the ethical implications of such research. Even one of the early pioneers in this field, Sanjiv Talwar, said: "There will have to be a major debate to determine whether this is appropriate or not", and "There are some ethical concerns here that I cannot deny."

Human and Sprague-Dawley rat brains were successfully connected using a brain-to-brain interface (BBI) developed by researchers at Harvard University. By using the BBI, the human is able to control the rat's tail simply by thinking the right thought. Both the human and the rat are equipped with

different types of computer-to-brain interfaces. The human uses an EEG-based brain-to-computer interface (BCI), whilst the rat uses a focused ultrasound interface (FUS) (CBI). Researchers are able to stimulate a specific group of neurons in a rat's brain using a method called FUS, which employs an ultrasonic signal (350 kHz ultrasonic frequency, pulse duration of 0.5 ms, pulse repetition frequency of 1 kHz, applied for 300 ms). The main advantage of FUS is that, unlike most other methods of brain stimulation, it is non-invasive. When a person stares at a specific pattern (a stroboscopic light flicker) displayed on a computer screen, the BCI sends a signal to the rat's CBI. This command causes ultrasound to be directed at the area of the rat's motor cortex responsible for controlling tail movement. According to the researchers' findings, the human BCI has an accuracy of 94 per cent, and the average time it takes for the rat's tail to wag in response to a person staring at the screen is around 1.5 seconds.

Dogs are often deployed in humanitarian aid, at crime scenes and on the battlefield; however, it is not always easy for them to understand the commands given to them by their handlers. Dogs can have a command module implanted into their bodies. This module contains a microprocessor, a wireless radio transmitter, a GPS receiver and a position and direction reference device, which is effectively a gyroscope. The command module sends vibration or sound commands to the dog, which are transmitted to the dog by the trainer via radio. These signals are designed to guide the dog in a specific direction or to perform a specific activity. The overall success rate of the control system was 86.6 per cent.

In 2005, the same researchers who were responsible for the remote control of a pigeon using brain implants carried out a successful experiment on mice using the same technology.

In 1967, Franz Huber pioneered the application of electrical stimulation to the brains of insects. He demonstrated that stimulating the mushroom bodies of insects can trigger complex

behavioural responses, including the inhibition of movement.

Backyard Brains, a company based in the United States, has launched the ‘RoboRoach’, a kit for building a remote-controlled cockroach, which the company bills as ‘the world’s first commercially available cyborg’. Concerns regarding the ethics of the research and the welfare of the animals used in it were raised from the outset when the project was launched as a senior design project for biomedical engineering students at the University of Michigan in 2010.

Another research team at North Carolina State University has created a cockroach that can be remotely controlled. Cockroaches were trained by researchers at NC State University, who used an Xbox Kinect to monitor their movements, to follow a predetermined course. The system made the necessary adjustments to the cockroach’s movements to keep it on the programmed course.

In tests funded by the Defence Advanced Research Projects Agency (DARPA) in 2009, the flight movements of Cotinus texana and the considerably larger Mecynorrhina torquata were remotely controlled. These beetles are

both members of the Cotinidae family (DARPA). Due to the additional weight of the electronics and batteries, only Mecynorrhina had the necessary strength to fly freely whilst being radio-controlled. It was prompted to fly by a predetermined sequence of pulses delivered to the insect's optic lobes. Although the longest flight ever recorded lasted more than 30 minutes, the average duration of a journey was only 45 seconds. The beetle returned to the ground after being prompted to do so by a single pulse. Stimulation of the basilar flight muscles enabled the controller to steer the insect to the left or right, although this was only effective in 75 per cent of cases. The flies were able to correct their course quickly after each turn and continue flying parallel to the ground. In 2015, the researchers were able to refine the fly's steering during flight by altering the pulse sequence delivered to the muscle responsible for folding the wings.

By using Drosophila, researchers have eliminated the need for stimulating electrodes and developed a three-part remote-control system that uses a laser beam to induce action potentials in predefined Drosophila

neurons. The ligand-gated ion channel, which is activated by ATP, serves as the primary gateway for the remote-control system. The application of ATP causes an increase in the uptake of extracellular calcium and the generation of action potentials. Chemically trapped ATP and laser light, which is capable of releasing the injected ATP, form the remaining two components of the remote control system. The chemically trapped ATP is injected into the fly's central nervous system via the simple eye, and the laser light is capable of releasing the injected ATP.

Insects have a mechanism in their brains known as the giant fibre system. This system consists of a pair of massive interneurons capable of activating the insect's flight and jumping muscles. Sixty to eighty per cent of the flies responded to a pulse of laser light lasting two hundred milliseconds by jumping, flapping their wings or engaging in other forms of flight. This frequency is higher than that induced by natural stimuli, such as a light-off stimulus, although it is lower than the frequency observed during direct electrical stimulation of the giant fibre system.

Spiny dogfish have had electrodes implanted, which are connected to a remote control unit located outside the tank. This allows the sharks to be controlled remotely. When an electric current is passed through the wire, it stimulates the shark's sense of smell, causing the animal to turn in the same direction as it would if blood were present in the water when the current is passed through the wire. The shark is made to turn more sharply in response to larger electrical pulses, which mimic the effect of stronger odours. One of the studies was made possible by a grant of 600,000 from the Defence Advanced Research Projects Agency (DARPA).

Researchers in South Korea have developed a control system that is entirely non-invasive and which enabled them to remotely control the movements of a tortoise. By influencing the natural tendency of red-eared sliders (Trachemys scripta elegans) to avoid obstacles in their path, the researchers were able to make the tortoises follow a predetermined route. When these turtles sense that something is obstructing their path in one direction, they will move in the opposite direction to avoid the obstacle. The researchers

attached a black half-cylinder to the turtle. The ‘visor’ was positioned around the rear end of the turtle but could be rotated either to the left or right using a microcontroller and a servo motor.

This allowed the ‘visor’ to partially obstruct the tortoise’s vision on one side. This led the tortoise to sense that there was a danger from which it needed to stay clear on that side, and as a result, the tortoise was prompted to move in the opposite direction.

Instead of having their entire bodies remotely controlled, parts of several animals’ bodies were manipulated remotely. Researchers in China used tiny stainless-steel electrodes to stimulate the midbrain of geckos (G. gecko) and to monitor the gecko’s responses during stimulation.

At various levels of the midbrain, it was possible to elicit locomotor responses such as bending of the spine and movement of the limbs. Ipsilateral bending of the spine was induced by stimulation of the periaqueductal grey, whilst contralateral bending of the spine was induced by stimulation of the ventral tegmental area.

In 2007, scientists at Shandong University of Science and Technology in eastern China inserted tiny electrodes into a pigeon's brain, enabling them to remotely control its flight in any direction – whether to the right, left, up or down.

It is believed that remotely controlled animals could serve a wide range of purposes, including eliminating the need for human presence in potentially dangerous situations. If equipped with a variety of additional electrical devices, their range of applications could be significantly expanded. It has been suggested that tiny animals fitted with cameras and other sensors could be useful in the search for survivors following a building collapse. Cockroaches and rats are examples of animals that are small and agile enough to navigate beneath rubble.

Some animals can be remotely controlled, but rather than being instructed to turn left or right, the animal's behaviour is modified in other ways, for example by preventing it from moving forward or by altering its behaviour in other ways.

Electric shock collars are radio-controlled electronic devices fitted into dog collars. These devices are programmed

programmed to deliver electric shocks of varying intensity and duration to a dog’s neck or other parts of its body. Some collar models feature an additional sound or vibration setting, which can be used instead of or in addition to the shock function.

Electric shock collars are now readily available and have been used in a wide variety of contexts, including behaviour modification, obedience training, pet control, and the training of military personnel, police officers and other service personnel. Although there are other types that may use comparable systems, the collars designed for domestic dogs are by far the most widespread.

The use of shock collars is the subject of heated debate, and the available scientific evidence regarding their effectiveness and safety is contradictory. Only a few countries have taken the initiative to ban or strictly regulate their use. There are animal welfare groups that both warn against their use and actively campaign for a ban on their use or sale. Some of them are seeking to impose sales restrictions on them. Whilst

some professional dog trainers and the organisations representing them oppose their use, others are in favour of it. There is a lack of consensus amongst the general public regarding their continued use or a ban on them.

In 2007, it was claimed that researchers working on a project called ‘Bovines Without Borders’ at the Commonwealth Scientific and Industrial Research Organisation had built a prototype of an ‘invisible fence’ using the Global Positioning System (GPS). To warn cattle when they approach a virtual barrier, the system uses battery-powered collars that emit a sound. If a cow gets too close, the collar emits an alarming sound to scare it away. Should it persist, the cow receives a 250-milliwatt electric shock. The boundary lines are determined by GPS and exist only as a line on a computer; they do not physically exist. There is not a single trace of cables or fixed transmitters anywhere. It took the cattle just under an hour to realise that, when they heard the warning sound, they should move away. According to the experts’ findings, it could take up to ten years for the system to be commercialised.

There are also wireless options for invisible fences. They do not use wire buried in the ground; instead, they transmit a radio signal from a central unit, which is activated when the animal moves beyond a certain distance from the unit.

{End of Chapter 6}

Chapter 7: Neural Engineering

Neural engineering, often known as neuroengineering, is a subfield of biomedical engineering that applies engineering principles to the study of neural systems, with the aim of better understanding, repairing, replacing or enhancing these systems. Engineers specialising in neural systems are particularly skilled at finding solutions to design challenges that arise at the interface between living brain tissue and non-living structures. (Hetling, 2008).

The disciplines of computational neuroscience, experimental neuroscience, neurology, electrical engineering and the signal processing of living neural tissue are all utilised within the field of neural engineering, which also encompasses aspects of robotics, cybernetics, computer engineering, neural tissue engineering, materials science and nanotechnology. Neural engineering is a relatively new field that is expected to play a significant role in the future of medicine and technology.

Restoring and enhancing human function through direct interactions between the human nervous system and artificial devices are two of the most important objectives in this field of research.

Understanding the encoding and processing of information in the sensory and motor systems, quantifying how this processing is altered in pathological conditions, and the ways in which it can be manipulated through interactions with artificial devices such as brain-computer interfaces and neuroprosthetics are the main focuses of much of the research being carried out today.

Research that focuses more on experimental investigation, such as the use of brain implants connected to external technology, is being carried out by other scientists.

Within the field of neural engineering, neurohydrodynamics is a sub-discipline that focuses on the hydrodynamics of the nervous system.

Given that neural engineering is still a very young field, the amount of information available

on the subject and the number of studies carried out is rather limited, although this is changing very rapidly.

The earliest publications in journals focusing exclusively on neural engineering appeared in 2004, when two new scientific journals were launched: *The Journal of Neural Engineering* and *The Journal of NeuroEngineering and Rehabilitation*.

Since 2003, the IEEE has organised and hosted a number of international conferences on neural engineering, including the Fourth International Conference on Neural Engineering in Antalya, Turkey, between 29 April and 2 May 2009; the 5th International IEEE EMBS Conference on Neural Engineering in Cancún, Mexico, in April/May 2011; and the sixth annual conference in San Diego. November 2013, in the state of California.

In April 2015, Montpellier hosted the 7th Annual Conference. In May 2017, Shanghai hosted the 8th Annual Conference.

The principles of neuroengineering involve linking neurons, neural networks and the operations of the nervous system with quantitative models to aid in the design

devices capable of reading and regulating signals and generating targeted responses.

Nerve impulses travel through the brain’s tissue and to the rest of the body, where they convey messages that the body uses to influence thoughts, sensations, actions and even its ability to survive. Neurons are highly specialised cells capable of transmitting signals that carry out higher- and lower-level processes necessary for survival and quality of life. Neurons are the fundamental functional unit of the nervous system. Neurons are also capable of transmitting these messages. Neurons are able to process information and then communicate this information to other cells because they possess unique electrochemical properties that enable them to do both simultaneously. The neuronal membrane potential and the changes that occur along and across it are both necessary for normal neuronal activation. Specific concentrations of certain ions are often responsible for maintaining a constant voltage—sometimes referred to as the membrane potential—across the membranes of neuronal cells. Any fluctuations

or shifts in this voltage lead to an imbalance, also known as polarisation, on the other side of the membrane. When the membrane undergoes depolarisation beyond its threshold potential, an action potential is generated.

Action potentials are the primary source of signal transmission in the nervous system, also known as neurotransmission. An action potential triggers a cascade of ion flows that travel through the axonal membrane. This generates an effective voltage spike, sometimes referred to as an ‘electrical signal’, which can transmit further electrical changes to other cells. Electrical, chemical, magnetic, optical and other types of stimuli can alter the movement of charges and voltage levels across neuronal membranes, which can lead to the generation of signals.

In this way, signals can be generated. (Er 2005). Quantitative tools used to understand and analyse complex brain systems are utilised by engineers. Researchers are able to modulate the activity of neural systems by employing methods that involve the investigation and generation of chemical, electrical, magnetic and optical signals

. These signals are responsible for extracellular field potentials and synaptic transmission in brain tissue (Babb et al. 2008). Engineers use signal processing methods and computer modelling to understand the characteristics of brain system activity (Eliasmith & Anderson 2003).

Neural coding is the process by which neural engineers must convert the voltages measured across neuronal membranes into a suitable code in order to process the transmitted signals. Research into neural coding has been conducted to gain a better understanding of motor and sensory phenomena. These studies focus on how the brain encodes fundamental directives in the form of central pattern generators (CPGs), movement vectors, the cerebellar internal model and somatotopic maps. In the field of neurology, the decoding of these signals refers to the process by which neurons interpret the voltages applied to them. Transformations are the processes by which signals of one type are processed and then converted into another form. These processes require a range of mechanisms. As a first step, engineers mathematically model these changes

(Eliasmith & Anderson 2003). These voltage signals can be recorded using a range of different approaches. These can be located either inside or outside the cell. Single-unit recordings, extracellular field potentials and amperometry are examples of extracellular approaches; more recently, multi-electrode arrays have been used to record and mimic signals.

The fields of neuroscience, biomechanics, sensation and perception, and robotics are all brought together within neuromechanics (Edwards 2010). Researchers use state-of-the-art methods and models to investigate the mechanical properties of neural tissues, as well as the effects of these properties on the tissue's ability to resist and generate force and movement, and its susceptibility to traumatic stress (Laplaca & Prado 2010). This sub-field of study focuses on translating the information exchanged between the neuromuscular and skeletal systems in order to define the functions and governing principles associated with the functioning and structure of these systems (Nishikawa et al. 2007). The simulation of neuromechanics is

possible by bridging the gap between computer models of neural circuits and models of animal bodies housed in virtual physical environments (Edwards 2010). To better understand the complexity of animal movement, researchers are currently investigating a wide range of topics, including the experimental analysis of biomechanics, which encompasses the kinematics and dynamics of movement; the process and patterns of motor and sensory feedback during movement; and the circuitry and synaptic organisation of the brain responsible for motor control. At the Georgia Institute of Technology, research in Dr

Michelle LaPlaca's laboratory focuses on investigating mechanical stretching in cell cultures, shear deformation in planar cell cultures, and shear deformation in three-dimensional cell-containing matrices. Once these processes are understood, the next step is to construct working models capable of characterising these systems in closed-loop conditions using specifically defined parameters. The study of neuromechanics aims to improve treatments for physiological health problems, including, amongst others, the

restoring mobility following injury, optimising the design of prostheses, and the development and control of mobile robots. Researchers are able to identify novel models of the mechanical properties of nerve cells by analysing structures in three-dimensional hydrogels. For example, LaPlaca et al. constructed a novel model demonstrating how stretching might play a role in cell culture (LaPlaca et al. 2005).

Neuromodulation is an approach to treating diseases or injuries that utilises medical device technologies to either stimulate or inhibit the activity of the nervous system. This is achieved by administering pharmaceutical agents, electrical signals or other forms of energy stimuli to restore balance in dysfunctional regions of the brain. Researchers in this field face the challenge of linking advances in the understanding of neural signals with advances in technologies that deliver and analyse these signals within closed loops in the brain with increased sensitivity, biocompatibility and viability. In this way, they hope to pave the way for the development of new treatments and clinical

applications that can treat patients suffering from a wide range of forms of neuronal damage. Unlike systemic therapies, which can have adverse effects on the body as a whole, neuromodulation focuses solely on treating very specific parts of the brain, making it an attractive option for treating a wide range of neurological disorders. Microelectrode arrays and other types of neuromodulator stimulators can stimulate and record brain activity, and with future development, they are expected to evolve into adaptive and responsive delivery systems for drugs and other types of stimuli. Neuroscience and engineering are combined in the fields of neural engineering and rehabilitation, with the aim of investigating the functioning of the peripheral and central nervous systems and developing practical remedies for problems caused by injuries or dysfunction in the brain. When applied to neuroregeneration, engineering focuses on developing devices and materials that promote the growth of neurons for specific applications.

These applications include the regeneration of damaged peripheral nerves, the regeneration of damaged spinal cord tissue and the regeneration of damaged retinal tissue. The fields of genetic engineering and tissue engineering are designing scaffolds for spinal cord reconstruction, which will help to alleviate neurological problems (Schmidt & Leach 2003).

Devices are used in research focusing on neural engineering to investigate how the nervous system functions and how it fails (Schmidt & Leach 2003).

The activity of neural networks, as well as the structure and function of the brain, can be investigated using various neuroimaging techniques. The terms ‘functional magnetic resonance imaging’ (fMRI), ‘magnetic resonance imaging’ (MRI), ‘positron emission tomography’ (PET) and ‘computed axial tomography’ (CAT) are examples of imaging technologies used in neuroimaging. Researchers interested in functional neuroimaging seek to identify which parts of the brain are responsible for various functions. The technique of functional

magnetic resonance imaging (fMRI) analyses haemodynamic activity, which is closely linked to cerebral activity. It is designed to map metabolic responses in specific areas of the brain in reaction to a particular stimulus or activity. PET, CT scanners and electroencephalography (EEG) are all currently under development and are likely to perform comparable functions in the near future.

Neural networks are a type of model that scientists can create by combining actual observations of neural systems with theoretical and computational models of these systems. The aim of this endeavour is to represent neural systems as realistically as humanly possible. The analytical capabilities of neural networks can be utilised to support the development of further neurotechnological devices. In particular, researchers use analytical or finite-element modelling to determine how the nervous system controls movement, and then apply this knowledge to help patients who have suffered brain injuries or diseases. Theoretical and computational models can be used to design artificial neural networks

, and these networks can then be implemented on computers, using either theoretical device equations or experimental conclusions based on observations of the behaviour of neural systems. The dynamics of ion concentrations, channel kinetics, synaptic transmission, single-neuron computation, oxygen metabolism and applications of dynamical systems theory could all be represented by models (LaPlaca et al. 2005). To create 3D neural networks from neuron-seeded microbeads, an assembly method based on a liquid stencil was employed.

When studying neural systems, or when augmenting or replacing neural functions with artificial devices, one of the most important tools available is known as a neural interface. Electrodes capable of selectively recording from associated electronic circuits to gather information about the activity of the nervous system, and of stimulating specific regions of nervous tissue to restore the function or sensation of that tissue, present a challenge for engineers (Cullen et al. 2011). The

mechanical properties of the brain tissue into which these devices are implanted must be compatible with the materials used in the devices, and any damage caused by the implants must be assessed. The temporary regeneration of biomaterial scaffolds or chronic electrodes is essential for neural interfaces, and it is necessary to regulate the body's response to the introduction of foreign substances. Recent technological developments, such as microelectrode arrays, enable the investigation of brain networks (Cullen & Pfister 2011). In optical neural interfaces, optical recording and optogenetics are used to make specific brain cells light-sensitive in order to modify the activity of these cells. Instead of electrodes, optical fibres can be implanted into the brain to record photon activity as a proxy for neural activity and to activate or silence specific neurons using light. This would be achieved through the use of light. Two-photon excitation microscopy enables the investigation of living neural networks as well as the communication processes between neurons.

The aim of brain-computer interfaces is to establish direct communication with the human nervous system in order to diagnose and treat intrinsic neurological disorders, as well as to monitor and activate neural circuits. Deep brain stimulation represents a significant advance in this field; it is particularly effective in treating movement disorders such as Parkinson's disease, using high-frequency stimulation of nerve tissue to suppress tremors. This is because deep brain stimulation works by stimulating the nerve tissue at a deeper level than conventional methods (Lega et al. 2011).

The ability to understand and transmit electrical, chemical, magnetic and optical signals to brain tissue is within reach thanks to the development of neural microsystems. They are capable of detecting fluctuations in membrane potential and assessing electrical parameters such as spike population, amplitude or rate via the use of electrodes, as well as by evaluating chemical concentrations, fluorescence intensity or magnetic field potential. The purpose of these systems is to transmit signals that influence the potential of the neural tissue

, which in turn stimulates the brain tissue to elicit the desired response. (Er 2005).

Microelectrode arrays are specialised devices used to identify the sudden voltage shifts that occur in extracellular environments as a result of the propagation of an action potential along an axon. Microfabricated 3D electrodes made from biocompatible materials such as SU-8 and SLA polymers were developed by Dr Mark Allen and Dr
LaPlaca. These electrodes have led to the development of in vitro and in vivo microelectrode systems that exhibit high compliance and flexibility to minimise tissue damage.

Neuroprosthetics are devices that can augment or replace lost functions of the nervous system by stimulating the nervous system and monitoring its activity.
Neuroprosthetics can achieve this in various ways. Electrodes that measure neuronal firing have the potential to connect to prosthetic devices and signal these devices to perform the function intended by the signal received. Artificial sensors are used in the construction of sensory prostheses to fulfil the role of missing

organic sources of brain information (He 2005). Engineers working on these devices are responsible for creating an artificial interface with nerve tissue that is stable, safe and durable. The cochlear implant is regarded as the most effective of these sensory prostheses, as it has enabled people who were previously deaf to regain their hearing. Visual prostheses, which can help blind people regain some of their visual abilities, are still in the early stages of research and development. Motor prostheses are devices that, through the use of electrical stimulation of the biological nervous and muscular systems, can serve as a substitute for the role of the brain or spinal cord in regulating movement. It is possible to replace lost limbs with smart prostheses controlled by neurological impulses. This can be achieved by transplanting nerves from an amputee's stump into the muscles. The conversion of mechanical inputs from the periphery into encoded information accessible to the nervous system is the function performed by sensory prostheses to provide sensory feedback to recipients.

The field of research known as neurorobotics investigates how mechanical representations of brain systems and the movements they control can be generated.

Neurorobots are often used in research covering motor control and locomotion, learning and memory selection, value systems and action selection, and so on. When neurorobots are studied in environments representative of the real world, it is much easier to observe and evaluate them in order to characterise the heuristics of the robot's operation in relation to its embedded neural systems and the responses of these systems to their environment (Krichmar 2008). For example, the effectiveness of a method for simulating seizure relief using a pseudo-spectral protocol has previously been demonstrated through the use of a computer model of epileptic spike-wave dynamics.

This model was used to demonstrate the success of the approach. The patient with idiopathic generalised epilepsy provided the computer model with a magnetic resonance imaging (MRI) dataset, which the model then used to simulate the brain's connections. The strategy

proved successful in generating stimuli capable of reducing the severity of seizures.

Neuroregeneration, also known as the regeneration of nerve tissue, is the process of attempting to restore the function of neurons that have been damaged either as a result of minor trauma or more severe trauma, such as that caused by a traumatic brain injury. Restoring a continuous pathway for axonal regeneration to the site of innervation is essential for the functional repair of damaged nerves. Researchers at the Georgia Institute of Technology, such as Dr LaPlaca, are using tissue engineering methods to identify a therapy that would aid in the repair and regeneration of damaged tissue following traumatic brain injuries and spinal cord injuries. Dr LaPlaca is investigating ways to deliver neural stem cells as minimally invasively as possible to the irregularly shaped lesions that occur following a traumatic shock. These approaches involve mixing neural stem cells with a protein-based scaffold derived from the extracellular matrix. Dr
LaPlaca’s laboratory aims to identify optimal strategies for

nerve regeneration following injury by studying neural stem cells in vitro, investigating alternative cell sources, developing novel biopolymers that could be used in a scaffold, and examining cell or tissue engineering grafts in vivo in models of traumatic brain and spinal cord injuries.

These activities are carried out to identify optimal strategies.

The repair of smaller gaps using autologous nerve grafts can be achieved by continuous surgical suturing of injured nerve ends. An autologous nerve graft obtained from another site in the body could be used for larger injuries. However, the procedure involving the use of an autologous nerve graft is time-consuming, expensive and involves two operations (Schmidt & Leach 2003). Clinical management of CNS is rather limited and focuses mainly on minimising collateral damage caused by bone fragments located in the immediate vicinity of the site of injury or inflammation. Patients undergo rehabilitation once the oedema surrounding the injury

has subsided. This is done so that the remaining nerves can be trained to compensate for the loss of nerve function in the damaged nerves. At present, there is no treatment capable of restoring nerve function in injured nerves within the central nervous system (CNS) (Schmidt & Leach 2003).

Creating an environment conducive to nerve regeneration is at the heart of the technical solutions being developed to treat spinal cord injuries. Until now, only nerve injuries to the peripheral nervous system (PNS) have been treatable in a clinical setting; however, recent developments in research involving genetic approaches and biomaterials suggest that spinal cord (SC) nerves may regenerate under suitable conditions.

There is a higher likelihood of biocompatibility with autologous tissue grafts, as they are made from natural materials. Furthermore, they provide structural support for nerves, which promotes cell adhesion and migration. These are all advantages of autologous tissue grafts (Schmidt & Leach 2003). Options such as non-autologous tissue, acellular grafts and extracellular matrix-based materials are all possibilities that have the potential to

serve as an excellent scaffold for nerve regeneration. Some are derived from allogeneic or xenogeneic tissues, both of which require the administration of immunosuppressants.

Amniotic tissue grafts and submucosa from the small intestine are two examples of the others (Schmidt & Leach 2003). As their physical and chemical properties can often be controlled, synthetic materials are desirable options. This makes them an attractive choice. The biocompatibility of synthetic materials remains an issue that needs to be resolved (Schmidt & Leach 2003). Constructs based on methylcellulose have been shown to be a biocompatible option that can serve this purpose (Tate et al.

2001). AxoGen models a human nerve using a method called AVANCE, which involves cell transplantation. It has been shown that 87 per cent of people with peripheral nerve damage can achieve remarkable recovery using this method.

Nerve guidance channels and nerve conduits are innovative strategies that target larger defects, providing a pathway for sprouting axons to direct their growth and overcome the growth inhibition caused by scar tissue

reduce. These tracts are also referred to as nerve guides or nerve conduits. Nerve guides must be easily shaped into a conduit of the required size, be sterile, tear-resistant and easy to handle and suture (Schmidt & Leach 2003). In an ideal scenario, they would degenerate over time as a result of nerve regeneration, be flexible and semi-permeable, retain their shape and have a smooth inner wall that mimics that of a real nerve (Schmidt & Leach 2003).

To promote neuronal regeneration, the delivery mechanisms must be managed with extreme rigour. The processes of development, survival, outgrowth and branching can all be influenced by neurotrophic agents. Nerve growth factor (NGF), brain-derived neurotrophic factor (BDNF), neurotrophin-3 (NT-3) and neurotrophin-4/5 (NT-4/5) are examples of neurotrophins. Other factors that induce a variety of brain responses include ciliary neurotrophic factor (CNTF), glial cell line-derived neurotrophic factor (GDNF), acid and basic fibroblast growth factors (aFGF, bFGF) and glial cell line-derived neurotrophic factor (GDNF). (Schmidt & Leach

2003). In rats with traumatic brain injury, it has also been shown that fibronectin promotes neuronal regeneration (Tate et al. 2002). Upregulated regeneration-associated genes (RAGs), neuronal cytoskeletal components and anti-apoptotic factors are some of the other therapeutic approaches being investigated. These approaches aim to regenerate nerves. GAP-43 and Cap-23 are examples of RAGs. Adhesion molecules such as the L1 family, NCAM and N-cadherin are also RAG components (Schmidt & Leach 2003). As a consequence of glial scar formation, there is also the possibility that inhibitory biomolecules in the central nervous system may be blocked. Some therapies currently under investigation include those involving chondroitinase ABC and the inhibition of NgR and ADP-ribose (Schmidt & Leach 2003).

To be effective, delivery systems must be biocompatible and stable within the living body. Osmotic pumps, silicone reservoirs, polymer matrices and microspheres are just a few examples of this type of material. Gene therapy approaches have also been investigated to enable the long-term synthesis of growth factors. These techniques can be carried out using viral or non-viral vectors such as lipoplexes

to facilitate delivery. Furthermore, cells are efficient carrier vehicles for extracellular matrix (ECM) components, neurotrophic factors and cell adhesion molecules. To promote the regeneration of neurons through transplantation, olfactory epithelial cells (OECs), stem cells and genetically modified cells have been used (LaPlaca et al. 2005, Schmidt & Leach 2003, Tate et al.
2002).

In novel therapies, complex conduction channels and multiple stimuli are combined to target internal structures that mimic the architecture of nerves and contain internal matrices of longitudinally aligned fibres or channels. These therapies have been developed to treat conditions such as multiple sclerosis, Parkinson's disease and Alzheimer's disease. Various methods, such as magnetic polymer fibre alignment, injection moulding, phase separation, solid free-form fabrication and inkjet polymer printing, can all be used in the manufacture of these structures (Schmidt & Leach 2003).

Another potential application of neuroengineering is the augmentation of human neurological systems, sometimes referred to as human enhancement through the use of

engineering methods. Patients undergoing deep brain stimulation as a treatment for neurological disorders have reported that this treatment has already improved their ability to recall previously stored memories. It is believed that some approaches to brain stimulation will be capable of shaping an individual's emotions and personality, increasing motivation, reducing inhibitions and fulfilling other requests made by the individual. As this research progresses, brain engineers will be confronted with a whole range of new considerations regarding the moral and ethical implications of human enhancements of this kind.

{End of Chapter 7}

Chapter 8: Single-cell recording

A microelectrode system is used in neuroscience to make single-unit recordings, which provide a means of assessing the electrophysiological responses of a single neuron. When a neuron generates an action potential, the signal travels through the neuron as a current, moving in and out of the cell across excitable membrane patches in the soma and axon. This allows the signal to be transmitted further down the neuron. The rate of change of voltage over time can be recorded by inserting a microelectrode into the brain, where it can then record the data.

Microelectrodes can be carefully positioned near the cell membrane to ensure the ability to record extracellularly. These microelectrodes must have tiny tips and high impedance.

The field of cognitive research makes extensive use of single-unit recordings, as this method enables the study of human cognition and cortical mapping. This information can then be used for technologies

known as brain-machine interfaces (BMI), which enable the brain to control external devices.

Electroencephalography (EEG), magnetoencephalography (MEG) and functional magnetic resonance imaging (fMRI) are just some of the methods that can be used to record brain activity. However, none of these methods is capable of resolving the activity of a single neuron.

The realisation that the nervous system possessed electrical properties was the first step towards developing the ability to record from individual units. Since then, single-unit recordings have evolved into a significant approach for gaining an understanding of the processes and activities carried out by the nervous system. Over the course of several years, single-unit recordings have continued to shed light on the topographical mapping of the cortex. The eventual development of microelectrode arrays made it possible to record from a range of different units simultaneously.

The 1790s: Luigi Galvani's work on dissected frogs in the 1790s provided the first evidence of electrical activity in the nervous system. Galvani's research led to the discovery

of this activity. He discovered that an electric spark could cause the leg of a dead frog to twitch in response to an electric current.

1888: Santiago Ramón y Cajal, a Spanish neurologist, revolutionised the field of neuroscience with his concept of the neuron and provided an explanation for the anatomy of the nervous system as well as the existence of its fundamental functional components, namely neurons.

In recognition of his contributions to this field, he was awarded the Nobel Prize in Physiology or Medicine in 1906.

1928: Edgar Adrian published *The Basis of Sensation*, which is regarded as one of the first reports to record activity from the nervous system. Adrian did this in 1928. In it, he discusses his recordings, made using a Lippmann electrometer, of the electrical discharges occurring in individual nerve fibres. He was awarded the Nobel Prize in 1932 for his work, which elucidated how neurons perform their functions.

In 1940, Renshaw, Forbes and Morrison carried out groundbreaking research by recording the discharges of pyramidal cells in the hippocampus of cats using glass microelectrodes.

In 1950, Woldring and Dirken published their findings that platinum wires could be used to record spike activity from the surface of the cerebral cortex.

The electrical activity in a cat's cerebral cortex was analysed in 1952 by Li and Jasper using the Renshaw, Forbes and Morrison technique.

Iridium microelectrodes were developed for recording in 1953.

Single-cell intracellular recording was the method used by John Eccles in 1957 to investigate synaptic processes in motor neurons (for which he was awarded the Nobel Prize in 1963).

Stainless steel microelectrodes were developed for recording in 1958.

1959: Studies by David H. Hubel and Torsten Wiesel. Tungsten electrodes were used to record the activity of individual neurons in cats that had not been anaesthetised and were allowed to move freely throughout the experiment. As a result of their work, they were awarded the Nobel Prize in 1981 for their work on information processing in the visual system.

1960: The development of glass-insulated platinum microelectrodes for recording purposes.

1967 was the year in which Marg and Adams published the first array of multi-electrode arrays used for recording. They employed this technique to record a large number of units simultaneously from a single patient in order to carry out diagnostic and therapeutic brain surgery.

In 1978, Schmidt and colleagues implanted chronically recording microcortical electrodes into the cortex of monkeys and demonstrated that they could teach the monkeys to control neuronal firing rates. This was a significant step towards the possibility of recording neuronal signals and utilising them for brain-machine interfaces (BMIs).

1981: Kruger and Bach constructed 30 separate microelectrodes and arranged them in a 5×6 layout before implanting the electrodes to record from multiple units simultaneously.

The Utah Intracortical Electrode Array (UIEA), a multi-electrode array capable of accessing the columnar structure of the cerebral cortex for neurophysiological or neuroprosthetic purposes, was developed in 1992.

In 1994, a planar silicon electrode known as the Michigan Array was developed. This electrode had many

reception sites. This invention served as the basis for the founding of the private neurotechnology company NeuroNexus.

In 1998, Kennedy and Bakay made a significant advance in BMIs through the development of neurotrophic electrodes. This was a crucial breakthrough for BMIs. They were able to successfully record action potentials using microelectrode arrays to control a computer cursor in patients with amyotrophic lateral sclerosis (ALS), a neurological condition that impairs a person’s ability to control voluntary movement. ALS is one of the most common forms of motor neuron disease.

Neuralink is a company dedicated to developing extremely high-bandwidth brain-machine interfaces (BMIs), which Elon Musk co-founded in 2016 and into which he has invested US$100 million. In 2019, he and Neuralink published their work, followed by a press conference that was broadcast live.

The ability to detect electrical impulses emitted by individual neurons is essential for single-cell recording.

When an electrode is inserted into an aqueous ionic solution, cations and anions tend to react with it. This creates an electrode-electrolyte interface.

When a microelectrode is inserted into an aqueous ionic solution, this tendency occurs. The process by which this layer forms is known as Helmholtz layer formation. A charge distribution takes place across the entire electrode, leading to the generation of a potential that can be measured relative to a reference electrode.

Microelectrodes, amplifiers, micromanipulators and recording devices are the basic pieces of equipment required for single-unit recording. The application determines the specific type of microelectrode used. During the signal amplification process, the high resistance of these electrodes presents several difficulties. A significant potential drop would occur across the microelectrode if it were connected to a standard amplifier with a low input resistance. Consequently, the amplifier would detect only a tiny percentage of the actual potential. To resolve this issue, you must use a cathode-follower amplifier as an impedance-matching device

to collect the voltage and then feed it to a standard amplifier. Micromanipulators are required for the precise implantation of an electrode into the brain in order to obtain a recording from a single neuron. This is of the utmost importance for recording single-unit activity within cells.

In the final step, the signals must be sent to some form of recording device. After amplification, the signals are filtered using a variety of different methods. Oscilloscopes and cameras can be used to record them, but more recent methods involve converting the signal into digital form using an analogue-to-digital converter and then outputting the data to a computer for storage.

Data processing methods can make it possible to isolate and analyse individual units.

Glass micropipettes and metal electrodes are the two main types of microelectrodes used for single-unit recording applications. Glass micropipettes and metal electrodes both have high impedance, but glass micropipettes have a much higher resistance, whilst metal electrodes have an impedance that varies with the

frequency. Glass micropipettes are the best tool for measuring resting and action potentials, whilst metal electrodes are the most effective choice for detecting extracellular spikes. Each type has a unique set of characteristics and limitations that may be advantageous when used in specific contexts.

To make the glass micropipettes conductive, an ionic solution is poured into them and they are then sealed; to establish an electrical connection, a silver-silver chloride (Ag-AgCl) electrode is immersed in the filling solution.

Ideally, the ionic solutions should contain ions comparable to those of the ionic species surrounding the electrode; it is important that the concentration within the electrode is the same as that in the liquid surrounding it.

Furthermore, the diffusive properties of the various ions contained within the electrode are expected to be comparable.

‘Providing a current-carrying capacity suitable for the purposes of the experiment’ is another requirement that the ion must fulfil.

Above all, it is essential that it does not induce any biological changes in the cell from which it is recording.

The use of potassium chloride (KCl) solutions is the most common application for Ag-AgCl electrodes.

When using electrodes consisting of Ag-AgCl, the interaction of ions with it leads to the generation of electrical gradients at the contact, thereby modulating the voltage over time.

Electrically, the resistance and capacitance of glass microelectrode tips are both very high.

They have a tip size of approximately 0.5–1.5 μm with a resistance of approximately 10–50 MΩ.

Due to the tiny size of the tips, it is easy to pierce the cell membrane whilst causing only minimal damage to intracellular recordings.

Micropipettes are well suited for measuring resting membrane potentials and, with a few minor optimisations, are also capable of recording action potentials.

When using glass micropipettes, there are a number of factors to bear in mind.

To compensate for the high resistance of glass micropipettes, you must use a cathode follower

as the initial stage of the amplifier.

Furthermore, high-frequency responses may be attenuated due to the high capacitance formed between the glass and the conductive fluid.

Both these electrodes and amplifiers inherently generate a certain amount of electrical interference.

Electrodes can be made from a variety of metals, the most common of which are silicon, platinum and tungsten. They ‘resemble a leaky electrolytic capacitor, as they exhibit very high impedance at low frequencies and low impedance at higher frequencies’.

The ability to monitor the activity of a single neuron has been made possible by single-unit recordings. For this reason, researchers have been able to determine the roles that different areas of the brain play in behaviour and function. More recently, it has been shown that recording from individual neurons is useful in the development of ‘mind-controlled’ gadgets.

To study the central nervous system (CNS), non-invasive technologies have been developed that provide information about its structure and function; however, these tools do not offer

particularly high resolution. To circumvent this problem, certain rather invasive recording techniques have been employed. Recording techniques that focus on a single unit offer a high degree of spatial and temporal resolution, making it possible to assess the relationship between the brain's structure, its functions and behaviour. By examining brain activity at the level of individual neurons, researchers are able to correlate brain activity with behaviour and develop neural maps that describe the flow of information through the brain. For example, Boraud et al. describe the use of single-unit recordings to determine the anatomical structure of the basal ganglia in patients with Parkinson's disease.

Over the past 20 years, brain-machine interfaces, often referred to as BMIs, have emerged. These devices are capable of decoding signals via a computer by recording the potentials of individual units and then outputting this signal to control an external device such as a computer cursor or a prosthesis. BMIs have the potential to restore function in people affected by neurological disorders or paralysis. This technology has the potential to

help a very wide range of patients, but it is not currently accessible in clinical settings as there is still insufficient reliability in signal acquisition over time. The fundamental explanation for this failure is that the continuous inflammatory response occurring around the electrode induces neurodegeneration, which limits the number of neurons from which it can record. (Nicolelis, 2001).

{End of Chapter 8}

Chapter 9: Hybrot

The term ‘hybrid robot’, abbreviated to ‘Hybrot’, refers to a cybernetic organism that takes the form of a robot and is controlled by a computer. It consists of both electronic and biological components. Typically, rat neurons are used as the biological components and are coupled to a computer chip.

Dr Steve Potter, Professor of Biomedical Engineering at the Georgia Institute of Technology, is regarded as the first person to have achieved this feat in 2003:

In this experiment, Potter drops a liquid droplet onto a silicon chip embedded with sixty electrodes and connected to an amplifier. The droplet contains thousands of rat neuron cells. The electrical signals that the cells send to one another are picked up by the electrodes, which then transmit the amplified signal to a computer. These signals are generated when the cells communicate with one another via electrical impulses. The data is then transmitted wirelessly from the computer to the robot.

This neural activity is subsequently manifested on the robot as physical movement, with each of the robot's movements being a direct consequence of neurons communicating with one another. Furthermore, the robot is capable of relaying information back to the cells. The robot is equipped with light sensors, and infrared signals along the walls of the running pen provide it with information about its position within the enclosure.

The difference between a cyborg and a hybrot lies in the fact that the latter term refers to a cybernetically enhanced person or a heikralically enhanced animal, whilst a hybrot is an entirely new form of creature made up of organic and artificial components. It may be helpful to think of the Hybrot as 'semi-living', a term also used by the people who invented the Hybrot.

{End of Chapter 9}

Chapter 10: Mark Gasson

Mark N. Gasson, who was recognised by the Guinness Book of Records in 2014 for his pioneering work in the field of implanted microchips in humans.

He is currently based in Los Angeles, in the state of California.

In 1998, Gasson graduated with a Bachelor of Science in Cybernetics and Control Engineering from the Department of Cybernetics at the University of Reading.

Between 2000 and 2005, Gasson was responsible for research involving the invasive connection of a person's nervous system to a computer. In 2002, a microelectrode array was implanted into the median nerve of a healthy human and connected percutaneously to a bespoke processing unit. This enabled the stimulation of nerve fibres to artificially generate sensations that were perceptible to the subject, as well as the recording of local nerve activity to generate control commands for wirelessly connected devices. Furthermore, the subject was able to

sensations produced by the artificial stimulation.

Together with neurosurgeon Tipu Aziz and his team at the John Radcliffe Hospital in Oxford, as well as physiologist John Stein from the University of Oxford, Gasson and his colleagues have been working on the development of deep brain stimulation for the treatment of movement disorders such as Parkinson's disease.

As part of the FIDIS project, which was funded by the European Commission and focused on various aspects of digital identity and privacy, particularly new technologies for identification and profiling, Gasson led a group of academics and industry experts from 24 institutions across Europe between 2004 and 2009. This group was brought together specifically for the project.

In addition to his articles on profiling, ambient intelligence and information and communication technology implants, Gasson underwent surgery in March 2009 to have a glass capsule containing an RFID device implanted in his left hand.

The implant was used as an identification device for the University of Reading's smart building infrastructure to gain access to buildings.

Gasson's smartphone was also fitted with a reader, so that the phone only worked when he was holding it.

In April 2010, following studies that highlighted the potential vulnerabilities of the implanted technology, the team led by Gasson demonstrated how a computer virus could infect his implant wirelessly and then be passed on to other devices.

Gasson drew comparisons with a variety of earlier surgically implanted devices, including those designed to increase heart rate, which he believed were vulnerable because manufacturers tended to adopt a philosophy of 'security through obscurity' rather than implementing effective security procedures.

Furthermore, he explained that, as implanted devices can restore or enhance bodily function, the boundaries of the body (i.e. the skin, which defines the human experience of bodily boundaries) are becoming increasingly blurred.

Consequently, there is no longer any meaningful distinction between human and machine, which means that the individual begins to regard the technology as part of their body and, as a result, it must be treated as such.

He argues that the evolution of our collective understanding of what constitutes our body and where its boundaries lie has led to two key implications, namely the following: Firstly, it is now possible to discuss matters from a human perspective, despite the fact that we are dealing with a scientifically enhanced human being, for example, one who is infected by a computer virus or allows their computer to be hacked by a third party.

His claim that he was the first person to be infected by a computer virus is supported by this evidence. Secondly, this extension of the idea that is regarded as a fundamental right

.

Gasson is an advocate of human enhancement through the use of technology surgically implanted into the body. He believes that the development of more sophisticated medical devices would ultimately lead to the creation of non-medical augmentation applications in humans.

Graham Cluley, a computer security blogger, criticised the research, stating that “predictions of pacemakers and cochlear implants being affected by viral infections are the worst kind of scaremongering”. (Predictions that

pacemakers and cochlear implants will be affected by viral infections are the worst kind of scaremongering.) Similarly, Barnaby Jack, a researcher working for the security firm McAfee, demonstrated an attack on an implanted insulin pump.

{End of Chapter 10}

Chapter 11: Visual Prosthesis

An experimental visual device, known as a visual prosthesis and sometimes referred to as a bionic eye, has been developed to restore functional vision in people suffering from either partial or complete blindness. Numerous devices have been developed, most of which are based on cochlear implants or bionic ear devices, both of which are examples of neural prostheses that have been in use since the mid-1980s. The concept of using electrical current (e.g. electrical stimulation of the retina or the visual cortex) to generate vision can be traced back to the 18th century.

Benjamin Franklin was one of the first to discuss the subject. The conditions under which a person loses their sight are a critical factor in determining whether or not a bionic eye can restore that person’s vision. Patients who have lost their sight as a result of photoreceptor degeneration (e.g. patients with retinitis pigmentosa, choroideremia or geographic atrophy-associated macular degeneration) are the best candidates for treatment with retinal prostheses, which are the

most common type of visual prosthesis currently being developed. Those who are candidates for visual prosthesis implants find that the operation has the best chance of success if the optic nerve had become established before the onset of blindness. It is conceivable that people born blind are born without a fully functional optic nerve, which normally develops before birth. However, neuroplasticity makes it possible for the nerve and vision to develop following implantation in certain cases.

Visual prostheses are currently being developed as a potentially helpful aid for those whose eyesight is deteriorating.

Within the European Union, only three visual prosthesis devices have received marketing authorisation.

In 2001, Dr Mark Humayun joined the teaching staff in the Department of Ophthalmology at the Keck School of Medicine, University of Southern California; this is a spiral-shaped cuff electrode designed in 2002 by Claude Veraart at the University of Leuven. It is placed around the optic nerve, which is located at the back of the eye. It is attached to a stimulator which has been implanted in a relatively small recess in the

skull. The stimulator is connected to an externally worn camera that transmits data to the device. These signals are then converted into electrical impulses and stimulate the optic nerve directly.

A small implanted telescope is a type of visual implant that has been shown to have a certain degree of effectiveness in the treatment of end-stage age-related macular degeneration. Technically, this type of visual implant is not regarded as an active prosthesis.

A team from southern Germany, led by Eberhart Zrenner of the University Eye Clinic in Tübingen, founded the company in 1995 with the aim of developing a subretinal prosthesis.

The chip is located beneath the retina and uses microphotodiode arrays (MPDA), which are responsible for collecting incident light and converting it into an electrical current to stimulate the retinal ganglion cells.

As natural photoreceptors are a highly effective alternative to photodiodes, the MPDA cannot be stimulated by visible light, as it lacks the necessary intensity.

An external power source is therefore used to amplify the stimulation current.

Experiments on living subjects were initiated by the German team in 2000, when evoked cortical potentials were measured in Yucatán micro-pigs and rabbits.

14 Months after the initial implantation, following an examination of the implant and the surrounding retina, no discernible changes to the anatomical integrity of the eye were observed.

In half of the animals subjected to the test, the implants were able to successfully generate evoked cortical potentials. The thresholds determined in this study were
comparable to those required for epiretinal stimulation
.

Subsequent reports from this group focused on the results of a pilot clinical trial conducted on 11 patients with retinitis pigmentosa.

There were some blind people who were able to read letters, identify unfamiliar objects, and locate a plate, a cup and some cutlery.

2010 marked the start of the multicentre trial, involving a device with 1,500 electrodes (Alpha IMS, manufactured by Retina Implant AG, Reutlingen, Germany), in a total of ten different patients; early results were presented at ARVO 2011.

In March 2012, Robert MacLaren of the University of Oxford and Tim Jackson of King's College Hospital in London performed the first implantations in the UK. Both institutions are based in London.

Joseph Rizzo and John Wyatt from the Massachusetts Eye and Ear Infirmary and MIT began researching the feasibility of a retinal prosthesis in 1989. Between 1998 and 2000, they conducted a series of proof-of-concept studies on epiretinal stimulation in blind volunteers. These studies successfully demonstrated the prosthesis's ability to stimulate the retina. Since then, they have developed a subretinal stimulator, which consists of an array of electrodes implanted beneath the retina in the subretinal region. It is capable of receiving image signals transmitted by a camera mounted on a pair of spectacles. The visual information transmitted by the camera

is decoded by the stimulator chip, which then activates the retinal ganglion cells in accordance with the decoding. Their second-generation prosthesis receives data and transmits it to the implant via high-frequency fields from transmitter coils located on the spectacles. This prosthesis is now in the testing phase. A secondary receiver coil has been sutured in place around the iris.

The microchip, containing 3,500 photodiodes, was invented in 2002 by brothers Alan Chow and Vincent Chow. These photodiodes detect light and convert it into electrical impulses that activate healthy retinal ganglion cells. The ASR does not require any externally worn devices.

A photovoltaic retinal prosthesis was developed in 2012 by Daniel Palanker and his team at Stanford University, The inner retinal neurons, located in the immediate vicinity of each pixel, are stimulated by an electric current flowing through the tissue between the active and return electrodes, primarily the bipolar cells, which are responsible for transmitting excitatory responses to the retinal ganglion cells.

Pixium Vision is the company working to bring this technology to market (PRIMA), and it is currently being investigated in a clinical trial (2018).

Having established this proof of concept, the Palanker Group is now focusing on developing pixels smaller than 50 μm using 3D electrodes and utilising the effect of retinal migration into cavities within the subretinal implant.

A company called Bionic Vision Technologies (BVT) has just acquired the research and commercialisation rights previously held by Bionic Vision Australia (BVA). BVA was a consortium comprising some of Australia's most prestigious educational institutions and research organisations. It began in 2010 with funding from the Australian Research Council, but ceased operations on 31 December 2016. The Bionics Institute, the University of Melbourne, UNSW Sydney, Data 61 CSIRO and the Centre for Eye Research Australia (CERA) were the institutions that participated in the research as members of the consortium. In addition, there were a large number of other partners. Bionic Vision Australia received an ARC grant from the Australian federal government

US$42 million from the Australian Federal Government to develop bionic vision technology. She later published a book entitled ‘I Spy with My Bionic Eye’ about her life, her vision loss and being the first person to have the BVA (Bionic Eye) device implanted. The book recounts her experiences as the first person to receive the device.

At the same time, BVA was working on the development of the High-Acuity device. This device combined a microprocessor with an implant containing 1,024 electrodes and incorporated a variety of new technologies into the process. The purpose of the device was to provide functional central vision, making it easier for users to carry out activities such as recognising faces and reading large text. The epiretinal approach would be used to place this high-acuity implant. Following the completion of pre-clinical research for this device in 2014, it was due to undergo patient trials; however, it is unclear whether these trials actually took place or not.

Patients suffering from retinitis pigmentosa were to be the first to take part in the trials, followed by patients with age-related macular degeneration. Each prototype contained

a camera attached to a pair of glasses. The signal was then transmitted to a microchip that had been surgically implanted in the eye. Once there, the signal was converted into electrical impulses that stimulated the neurons in the retina that were still healthy. The information was then sent via the optic nerve to the areas of the brain responsible for visual processing.

On 2 January 2019, BVT announced the successful results of a series of tests carried out on four people from Australia using an updated version of the device. Earlier models of the device were intended for short-term use only, but the new design made it possible to use the technology continuously and, for the first time, even take it outside the laboratory – for example, into the home. Further implants are due to be made available during 2019.

The device, developed by Harvard and MIT, is functionally comparable to this one, with the exception that the stimulator chip is implanted in the primary visual cortex rather than on the retina. Implants have been fitted to a large number of people with a high success rate and few side effects.

When Dobelle died in 2006, the project had only just got off the ground

and was still in the planning phase; nevertheless, it was decided that the eye should not be sold for profit, but should be donated to a research group funded by public money.

In 2009, the Laboratory for Neural Prosthetics at the Illinois Institute of Technology (IIT) in Chicago began constructing a visual prosthesis using intracortical electrode arrays. Although similar in concept to the Dobelle system, the use of intracortical electrodes enables significantly improved spatial resolution of the stimulation signals (more electrodes per unit area). Furthermore, work has begun on the development of a wireless telemetry system.

{End of Chapter 11}

Chapter 12: Microelectrode Arrays

Microelectrode arrays (MEAs), also known as multi-electrode arrays, are essentially neural interfaces that connect neurons to electronic circuits. These devices contain multiple microelectrodes – ranging from tens of thousands to thousands of them – through which neural signals can be received or transmitted. MEAs are also referred to as microelectrode arrays. Implantable MEAs, which are used in vivo, and non-implantable MEAs, which are used in vitro, are the two main categories of MEAs.

When neurons and muscle cells are activated, the ionic currents flowing across their membranes create a voltage difference between the interior and exterior of the cell. During the recording process, the electrodes of an MEA convert the fluctuating voltage from the environment, which is carried by ions, into currents carried by electrons (electronic currents). When stimulated, the electrodes convert the electronic currents flowing through them into ionic currents flowing through the medium. This causes the voltage-gated ion channels,

located on the membranes of excitable cells, to be activated; this depolarises the cell and triggers an action potential if the cell in question is a neuron, or a twitch if the cell in question is a muscle cell.

The amplitude and shape of a recorded signal are determined by a number of factors, including the nature of the medium in which the cell or cells are located (e.g. the electrical conductivity, capacitance and homogeneity of the medium), the nature of the contact between the cells and the MEA electrode (e.g. the contact area and the tightness of the contact), the nature of the MEA electrode itself (e.g. geometry, impedance and noise) and the analogue signal processing (e.g. sampling rate and digital signal processing). For the recording of a single cell that only partially covers a planar electrode, the voltage at the contact pad is approximately equal to the voltage across the overlapping region of the cell and the electrode, multiplied by the ratio of the area of the overlapping region to the area of the entire electrode, or it can also be expressed as the voltage of the overlapping region multiplied by the voltage of the overlapping region multiplied by the voltage of the overlapping region multiplied by the voltage of:

$$V_{pad} = V_{overlap} \times \frac{A_{overlap}}{A_{electrode}}$$

Assuming that the region around an electrode is well insulated and has only a negligible capacitance. In order to obtain strong signals from dissociated cultures, it is crucial that the cells adhere appropriately to the MEA substrate.

Microwire arrays, developed in the 1950s, were the first implantable arrays ever developed. The use of MEAs in research was also possible at a variety of other institutions.

Microelectrode arrays can be divided into the following subcategories depending on their potential applications: arrays used both in vitro and in vivo.

The typical configuration for an in vitro MEA consists of either 8 × 8 or 6 × 10 electrodes arranged in a grid.

Electrodes are typically made of indium tin oxide or titanium and have diameters between 10 and 30 μm.

Single-cell cultures or acute brain slices are often the applications for which these arrays are used.

Micro-wire, silicon-based and other types of MEAs are the three primary types of implantable MEAs; at least from an electrical perspective, the action potential serves as the primary unit of communication between neurons. The axon hillock is where this all-or-nothing phenomenon begins. Generally speaking, the main advantages of using in vitro arrays over other, more conventional approaches, such as
e.g. patch clamping, are as follows:

Instead of having to implant each electrode separately, it is now possible to insert numerous electrodes simultaneously.

The ability to set up controls within the same experimental environment as the main experiment (by using one electrode as a control and others for the experimental conditions). This is of particular importance when conducting research involving stimulation.

The ability to select different recording sites within the array.

The ability to receive data simultaneously from a range of different locations

The ability to provide visual stimulation in real time is one reason why recordings from intact retinas are of such great interest. Another reason is the possibility of reconstructing receptive fields, which is also possible with these recordings.

Furthermore, in vitro arrays are less invasive than patch clamping, as they do not require the cell membrane to be breached. This is because, in patch clamping, the cell membrane is breached.

Compared to patch clamping, however, in vivo arrays have a far higher spatial resolution, which is one of their main advantages. Signals can be recorded from individual neurons using implantable arrays, allowing information such as the location or speed of motor movement to be used to operate a prosthesis. This information can also be used to control prostheses.

In rats, at least, it is conceivable to make large-area, parallel recordings during the animal's activity using dozens of implanted electrodes. Extracellular recording is therefore the technique of choice when it comes to identifying brain circuits and investigating how these circuits function

. To date, however, the issue of unambiguously identifying the recorded neuron through the use of extracellular multi-electrode arrays remains a challenge.

In vitro MEAs have lower spatial resolution than patch-clamp and dynamic clamp systems; consequently, they are not as well suited to the recording and activation of individual cells as these two other types of devices. Compared with the capabilities of dynamic clamps, the complexity of the signals that an MEA electrode could efficiently transmit to neighbouring cells is severely limited.

Particularly with regard to chronic implantation, there are also a number of biological reactions that may occur following the implantation of a microelectrode array. The most significant of these effects are neuronal cell death, glial scarring and a reduction in the number of electrodes that remain functional.

Compared with in vivo models, the nature of dissociated neuronal networks does not appear to alter or diminish the character of their pharmacological response. This suggests that MEAs can be used to

investigate the pharmacological effects on dissociated neuronal cultures in an environment that is simpler and more easily controlled. It was not possible to determine with absolute certainty the specific neuronal coding strategy used to control the robot's behaviour.

It was possible to investigate the firing of networks in hippocampal slices using MEAs.

Deep brain stimulators, cochlear implants and pacemakers are just some of the implanted interfaces now available to consumers. Other implantable interfaces include hearing aids. The use of deep brain stimulation, often known as DBS, has proven to be a successful treatment for movement disorders, including Parkinson's disease. A scientific user conference is held every two years in Reutlingen, organised by the Institute of Natural Sciences and Medicine (NMI) at the University of Tübingen.

The symposia provide a comprehensive overview of all topics related to new advances and current applications of microelectrode arrays in basic and applied neuroscience, as well as in industrial

drug research, [citation needed], safety pharmacology and neurotechnology.

The biennial conference has developed into an international forum for researchers from industry and academic institutions who develop and utilise MEAs, ... and is renowned as a high-quality scientific forum brimming with knowledge.

Open-access books have been made available for the presentations given during the conference.

In addition to applications within the scientific community, contemporary art has utilised MEAs to address philosophical issues concerning the relationship between technology and biology.

Historically, in Western philosophy, biology and technology have been divided into two distinct categories: bios and technê.

{End of Chapter 12}

Chapter 13: Cyborg

A cyborg (/ˈsaɪbɔːrg/) – a portmanteau of ‘cybernetic’ and ‘organism’ – is a being with both organic and biomechatronic body parts.

Manfred Clynes and Nathan S. Stratton coined the term in 1960. Kline.

The term ‘cyborg’ does not refer to the same thing as bionics, biorobotics or androids; rather, it describes an organism that has either regained function or enhanced its capabilities as a result of the integration of an artificial component or technology that relies on some form of feedback. Cyborgs are often depicted as mammals, including humans; nevertheless, it is not ruled out that they might be any other form of creature.

In the foreword to D. S. Halacy’s 1965 book *Cyborg: Evolution of the Superman*, the author speaks of a ‘new frontier’ which ‘is not merely outer space, but lies deeper: the connection between “inner space” and “outer space” – a bridge … linking thought and matter.’

According to Donna Haraway, there has been a love-hate relationship between humanity and machines and technology for as long as machines and technology have existed. This has been the case throughout history. Haraway is at the forefront of this movement and analyses the complex relationship that exists between humans and technology.

Her thoughts on cyborgs and the path humanity is taking towards the concept of cyborgs are set out in the Cyborg Manifesto, which she published. There is nothing extraordinary or unique about Haraway, apart from the fact that she describes herself as a cyborg and is the product of science and technology. In today's world, humans and technology are so intertwined that it is difficult to pinpoint where one ends and the other begins. This is particularly evident in the field of medicine, thanks to the advances made possible by the convergence of contemporary science and technology.

As the human race continues to evolve as a civilisation, Haraway argues that all distinctions between humans, animals and technological defences have been blurred.

This breakdown leads to hybrids as well as to an increase in complexity.

Wherever you look, there is some form of technology that people need and on which they depend.

Given how far science and technology have come, we are now dependent on them even for the smallest daily activities.

In a sense, we are entering a cyborg era.

Just as Haraway's world is filled with these tangled networks of humans and machines, our bodies are, in and of themselves, networks.

It is not as natural as is often assumed; food is provided for this purpose, medicines are what keep it alive, and it is modified through the use of medical practices.

Haraway believes that, in order to survive, we must grapple with the complex structure of technoculture. This article can also be read from a feminist perspective
if you so wish.

Throughout history, women have always been told that they are 'by nature' weak, submissive and overly emotional.

But if we are cyborgs, as Haraway suggests, then it will be possible to reshape and enhance us all.

There is the possibility of creating a new identity for yourself, your sexuality and everything else, entirely according to your wishes. Since we are the ones who have made it possible for machines and technologies have reached such a high level, we really need not be afraid of the things we have created. As cyborg identities are now part of human identities, they should be welcomed with open arms. Holding just one point of view can lead to more problems than it solves, so it is important to try to understand things from the other side's perspective as well.

According to certain interpretations of the word 'cyborg', people who have even the most basic physical connections to their technology are already considered examples of this category. As these devices can measure voltage potentials in the body, process signals and deliver electrical stimuli, a person with an artificial pacemaker or an implantable cardioverter-defibrillator would, in a typical example, be regarded as a cyborg. Cyborg enhancements also include implants,

in particular cochlear implants, which combine a mechanical modification with some form of input response. As examples of humans being equipped with technology to enhance their biological capabilities, some theorists point to modifications such as contact lenses, hearing aids, mobile phones and intraocular lenses.

Some theorists argue that new definitions of ageing are necessary, as the number of cyborgs being created today is increasing. (One example of this would be the proposed biotechno-social definition of ageing.) Motorways, pipelines, electrical cables, buildings, power stations, libraries and other infrastructure that people scarcely notice, but which are crucial aspects of the cybernetic environment in which people operate, are examples of cybernetic technology.

In the Shaper/Mechanist world created by Bruce Sterling, he developed the concept of an alternative cyborg, which he called a ‘Lobster’. Lobsters are not constructed using internal implants, but by means of an external shell (e.g. a powered exoskeleton). Unlike human cyborgs – also known as ‘Bishops’ from the *Alien* series – Lobsters appear inhuman on the outside, but actually harbour

a human being. Human cyborgs look human on the outside but are artificial on the inside (as in *Elysium* and *RoboCop*).
Cyborgs named Omar – which is the Russian word for ‘lobster’ – feature prominently in the video game *Deus Ex: Invisible War*.

The most common depiction of a cyborg in science fiction is that of a human (or, less commonly, an animal) to whom apparent mechanical elements have been added. These include the DC Comics superhero Cyborg and the Borg species from the Star Trek lore universe.

On the other hand, cyborgs can also be depicted as having an appearance that is either more robotic or more organic. They may appear as humanoid robots, such as Robotman from DC’s Doom Patrol or most variants of the Cybermen from Doctor Who; they may appear as non-humanoid robots, such as the Daleks (again from Doctor Who) or the majority of the Motorball players in Battle Angel Alita and its prequel, Ashen Victor; and they may appear as any combination of the two.

Cyborgs with a more human appearance, such as Darth Vader or Misty Knight from Star Wars, may choose to

mechanical components by covering them with armour or clothing (Marvel Comics). Cyborgs are artificial beings that combine human and mechanical characteristics. For example, the eponymous Six Million Dollar Man and the Bionic Woman (from their respective television series) have prosthetics that appear outwardly identical to the body parts they have replaced. On the other hand, Major Motoko Kusanagi (Ghost in the Shell) is a full-body cyborg whose body appears to be human. It is not uncommon for cyborgs to possess superhuman (physical or mental) qualities, such as immense strength, enhanced senses, computer-aided intellect or built-in weaponry, as demonstrated in the examples mentioned above and in a number of other works of fiction.

Before the Second World War, there was a great deal of science fiction that explored the idea of human-machine collaboration.

As early as 1843, Edgar Allan Poe wrote in his short story ‘The Man That Was Used Up’ about a character who had a vast number of prosthetic limbs.

In 1911, ‘The Nyctalope’ was first described by Jean de La Hire, a protagonist in a work of science fiction

who is regarded as the first literary cyborg, in *Le Mystère des XV* (later translated as *The Nyctalope on Mars*).

More than two decades later, in his story ‘The Comet Doom’, published in 1928, Edmond Hamilton imagined space travellers with a combination of biological and mechanical components.

It subsequently became a talking point, the still-functioning mind of an experienced researcher, Simon Wright, floating all alone in a clear container, in every single one of his famous exploits as Captain Future.

In 1944, the short story “No Woman Born” by C.

L.

Moore wrote a few words about Deirdre, a dancer whose body had been completely destroyed by fire and whose brain had been transplanted into an anonymous, nameless, yet beautiful and supple artificial body.

In 1960, Manfred E. Clynes and Nathan S. Kline developed the concept of an enhanced human capable of thriving in alien environments. They referred to this

concept as a ‘cyborg’ and coined the term ‘cyborg’ to describe it:

We propose that the word ‘cyborg’ refers to an exogenously augmented organisational complex that unintentionally functions as an integrated homeostatic system.

Their idea arose as a result of their reflections on the need for an intimate relationship between human and machine, at the very time that a new frontier in space exploration was becoming accessible. Clynes was chief scientist at the Dynamic Simulation Laboratory at Rockland State Hospital in New York. He was also a designer of physiological equipment and electronic data-processing systems.

When Clynes and Kline first presented their paper five months earlier at the ‘Psychophysiological Aspects of Space Flight Symposium’, the New York Times was the first publication to use the term ‘psychophysiological aspects of space flight’:

A cyborg is essentially a human-machine system in which the control mechanisms of the human component are externally modified by medication or regulatory devices

so that the being can exist in an environment different from that in which it would normally be found.

According to this, Hamilton would be the first person to openly use the word ‘cyborg’ to describe the ‘mechanical analogues’ known as ‘Charlies’ in the 1962 short story ‘After a Judgment Day’. He would explain that ‘[c]yborgs—they had been called, from the very beginning in the 1960s… cybernetic beings.’

In 2001, Doubleday published the book *Cyborg: Digital Destiny and Human Possibility in the Age of the Wearable Computer*. The book’s subtitle was ‘Digital Destiny and Human Possibility in the Age of the Wearable Computer’. In the same year as its publication, the documentary *Cyberman* explored some of the themes presented in the book.

In artificial tissue engineering, cyborg tissues constructed using carbon nanotubes and plant or fungal cells have been used to develop novel materials that can be utilised for mechanical and electrical applications.

At the spring meeting of the Materials Research Society on 3 April 2013, researchers including Raffaele Di Giacomo and Bruno Maresca presented their findings.

The C-Limb system, developed by Otto Bock HealthCare, is currently used in the field of prosthetics to replace a human leg that has been amputated as a result of illness or an accident. The artificial C-Leg attempts to replicate the user's natural gait, as it was before the amputation, through the use of sensors, which significantly improves the user's ability to walk with the device. Some people believe that prostheses such as the C-Leg and the more sophisticated iLimb represent the first real steps towards the next generation of practical applications for cyborg technology in the real world. Furthermore, cochlear implants and magnetic implants, which give individuals a sense they would not otherwise have had, can be seen as contributing to the emergence of cyborgs.

In the field of vision research, direct brain implants have been used as a method of treating acquired (as opposed to congenital) blindness. William Dobelle, a private researcher, was one of the first scientists to develop a

brain-computer interface designed to restore sight. He was one of the pioneers in this field. In 1978, Dobelle's first prototype was surgically implanted into 'Jerry', an adult man who had been born blind. Jerry's visual cortex was implanted with a single-array brain-computer interface (BCI) comprising 68 electrodes. This proved successful in generating phosphene, which is the sensation of seeing light. To transmit signals to the implant, the device used cameras mounted on a pair of spectacles. At first, Jerry could only see different shades of grey with a limited field of view and a slow frame rate, as the implant was still being adapted; this also required him to be connected to a mainframe computer weighing two tonnes. However, as electronics have become smaller and computers faster, his prosthetic eye has become more portable, and he is now able to carry out basic activities without assistance. A leading advocate for the rights of cyborgs worldwide is Neil Harbisson.

Rob Spence, a filmmaker from Toronto who describes himself as a 'real Eyeborg', suffered severe injuries to his right eye as a teenager following a shooting accident that

on his grandfather's farm. Many years later, in 2005, he decided to have the eye – which had steadily deteriorated and was now clinically blind – surgically removed. bodyNET is a human-electronics interface programme currently being developed by researchers at Stanford University.

The RoboRoach was developed by Backyard Brains, a company based in the United States. The company claims that it is the 'world's first commercially available cyborg'. The idea for the project originated in 2010 as a senior design project for a biomedical engineering student at the University of Michigan. The kit enables students to use microstimulation to temporarily control the movements of a walking cockroach by using a Bluetooth-enabled smartphone as a controller.

Concerns regarding the ethics of the experiment and the welfare of the creatures involved have been raised by other research institutions that have created cyborg insects, such as those at North Carolina State University.

In the late 2010s, scientists used a microelectronic prosthesis to construct cyborg jellyfish.

This prosthesis enables the animal to move about three times faster, whilst consuming only twice as much metabolic energy as its unmodified counterparts. It is possible to remove the prosthesis without harming the jellyfish.

Both restorative and augmented cyborgs play a significant role in the field of medicine, but differ markedly from one another. “Lost functions, organs and limbs can all be restored” with the help of restorative technology. The essential component of restorative cyborgisation is the act of repairing damaged or missing processes in order to restore either a healthy or average level of functioning. There is no enhancement of the fundamental abilities and operational procedures that have been lost.

On the other hand, the enhanced cyborg ‘adheres to a principle, and that principle is the concept of optimal performance: maximising output (the information captured or changes made) and minimising input (the amount of energy consumed in the process)’. Therefore, the purpose of the enhanced cyborg is to go beyond the capabilities of standard procedures

or even to acquire new capabilities that were not originally available.

Although prostheses generally replace missing or injured body parts by integrating a mechanical substitute, bionic implants used in medicine enable model organs or body parts to replicate their original function more accurately. *Rebuilt: How Becoming Part Computer Made Me More Human* is the title of a book written by Michael Chorost about his experiences with cochlear implants, sometimes known as bionic ears.

Another example of cyborgisation in the medical field is the use of retinal implants. People suffering from conditions such as retinitis pigmentosa and age-related vision loss (conditions in which people have an unusually low number of retinal ganglion cells) may be candidates for retinal stimulation, in the hope of restoring their vision. According to the theory behind retinal stimulation, the retinal implant and electrical stimulation would act as a substitute for the missing ganglion cells (cells that connect the eye to the brain).

Although there is still much work to be done to develop this technology, significant progress has already been made in using electrical stimulation of the retina to enable the eye to detect patterns of light. The patient must wear a special camera, for example attached to the frames of their glasses; this camera then transmits the image to a computer, where it is converted into a pattern of electrical stimulation. A chip implanted in the user's eye would then electrically stimulate the retina with this pattern by activating specific nerve endings. These nerve endings are responsible for transmitting the image to the brain's visual centres, which would then enable the user to see the image. This technology has the potential to be used by thousands of blind people, enabling the majority of them to regain their sight. If scientific progress continues as expected,

people who have lost their vocal cords may now receive support through the development of a similar method. The robotic-sounding speech simulators used in the past could become obsolete as a result of this experimental technology. The transmission of

sound would begin with a surgical procedure to reroute the nerve that regulates the production of the voice and other sounds to a muscle in the neck, where a nearby sensor could pick up its electrical signals. This would enable the signals to be transmitted. The signals would then be sent to a processor responsible for regulating the timing and pitch of a speech simulator. The vibrations generated by this simulator would then produce a multi-tonal sound that the user's tongue could manipulate into words.

Recent research carried out by several military groups has focused on the concept of using cyborg insects to achieve the purported aim of gaining a tactical advantage. The Defence Advanced Research Projects Agency (DARPA) has shown an interest in creating 'cyborg insects' that would be capable of transmitting data via sensors implanted into the insect whilst it was in the pupal stage. The insect's movement would be controlled by a microelectromechanical system (MEMS), and it would be possible to survey its surroundings or detect bombs and gases.

It took place in Zurich, Switzerland, and was the first international and official celebration of cyborg sport. The Cybathlon became the first Cyborg Olympics in 2016. In this competition, 16 teams, made up of people with disabilities, transformed themselves into cyborg athletes by utilising various technological advances. There were a total of six different events, and the participants used and operated cutting-edge technology such as powered leg and arm prostheses, robotic exoskeletons, motorbikes and motorised wheelchairs.

Nevertheless, one of the main aims of the event, as well as the simpler activities, is to demonstrate how technological advances and more sophisticated prosthetics can transform people's lives. The next Cybathlon, which was due to take place in 2020, has had to be postponed due to the widespread coronavirus pandemic.

The term 'cyborg' is most commonly used in the context of science fiction works. However, many artists have sought to raise awareness of cybernetic beings amongst the general public. These attempts can take the form of both paintings and installations

. There are a number of artists, including Neil Harbisson, Moon Ribas, Patricia Piccinini, Steve Mann, Orlan, H. R. Giger, Lee Bul, Wafaa Bilal, Tim Hawkinson and Stelarc, who are responsible for producing such works.

As a performance artist, Stelarc has visually explored and audibly amplified his body to create his work. His exploration of alternative, intimate and involuntary interactions with the body is carried out through the use of medical devices, prostheses, robotics, virtual reality systems, the internet and biotechnology. In addition to his performance featuring a third hand and a virtual arm, he has also produced three videos showing the interior of his body. Between 1976 and 1988, he carried out a total of 25 body-suspension acts, which also involved the insertion of hooks into his skin. As part of his performance piece entitled ‘Third Ear’, he underwent surgery to physically create an additional ear in his arm. This ear was connected to the internet, enabling people in other locations to use it as an acoustic instrument.

The concept of the cyborg has been explored by artists from the imaginative perspective of their craft. Some people are working to develop a vision of the union of

Bringing the relationship between technology and the human body – which is purely conceptual – into the realm of art by using a variety of media, ranging from sculptures and drawings to computer-generated imagery. Cyborg artists are those who create art with the intention of turning cyborg-based dreams into reality. These artists generally refer to themselves as cyborg artists or regard their artworks as cyborgs. The flexibility with which an interpretation approaches the word ‘cyborg’ determines the way in which an artist or their work can be categorised as a ‘cyborg’.

Scholars who rely on a strict, technical definition of a cyborg – often based on Norbert Wiener’s cybernetic theory and Manfred E. Clyne and Nathan S. Kline’s initial use of the term – would likely argue that the majority of cyborg artists do not meet the criteria to be regarded as cyborgs. This is due to Norbert Wiener’s cybernetic theory and Manfred E. Clyne and Nathan S. Kline’s initial use of the term.

It is well known that the field of body modification draws upon a range of medical technologies, procedures and advances as the field of medicine continues to evolve.

Although there are as yet no cyborgs in the sense in which Manfred Clynes and

Nathan Kline, technological developments such as implantable silicon-silk electronics would combine the aesthetics of body modification with interactivity and functionality, bringing a transhumanist way of life into the present day.

Furthermore, the manifestation of anxiety is a possibility that should not be overlooked. Individuals may suffer from feelings of anxiety and anxiety disorders prior to the implantation process. To this end, individuals may also experience feelings of unease, particularly in a socialised environment, due to their post-operative, technologically augmented bodies and a mutual unfamiliarity with the mechanical implants. This is particularly true when the social environment is one in which individuals interact with one another. It is possible that their fears are linked to notions of otherness or a cyborg identity.

Transporting humans into space is, by its very nature, a risky endeavour, and in the not-too-distant future, various cyborg technologies may be employed as a means of mitigating these risks. Experiments carried out to date

have so far only resulted in patients being in a state of suspended animation for a week. The cost of a mission to Mars could be reduced if technological advances enabled astronauts to enjoy a deeper sleep for longer periods. This would lead to lower resource consumption by the astronauts.

Some theorists, such as Andy Clark, believe that the interactions taking place between humans and technology will ultimately culminate in the establishment of a cyborg system. In this conception, a cyborg is understood as a hybrid system that combines biological and mechanical elements, thereby leading to an enhancement of the biological component whilst simultaneously producing a more complex whole. Clark argues that an understanding of human cognition requires an extension of this concept in order to grasp it fully. He believes that the mechanical component of a cyborg system could be any device used to offload part of a cognitive activity. For example, a computer could be regarded as a mechanical component.

Examples of this human-technology cyborg system can be very basic and simple, such as the use

a pocket calculator to perform basic mathematical operations or pen and paper to take notes, or they can be as high-tech as the use of a PC or a mobile phone. Both examples are cyborg systems that combine human and technology. According to Clark, these interactions between a person and a form of technology integrate that technology into the cognitive process in a manner analogous to the way in which a technology that would correspond to the traditional concept of cyborg augmentation is integrated with its biological host. In particular, these interactions integrate this technology in a way analogous to how a technology that would fit the traditional concept of cyborg augmentation is integrated into its biological host. Clark concludes that we are ‘naturally born cyborgs’ because every single person uses technology to enhance their cognitive processes in some way.

Given the existing and future technological capabilities of implanted sensory and telemetric devices, the number of such devices—all of which will be connected to various

commercial, medical and government networks, will increase significantly. For example, patients will be able to log on to their home computers and access virtual doctors' surgeries and medical databases, as well as receive medical prognoses from the comfort of their own homes, based on the data collected by their implanted telemetric devices. This will take place within the medical industry. Patients will also be able to receive medical prognoses from their implanted telemetric devices.

The Cyborg Foundation was established in 2010 as the world's first multinational organisation dedicated exclusively to supporting people in their quest to become cyborgs.

The concept of cyborgs is widely featured in works of science fiction literature as well as in other forms of media. 'Cyborg' is a term often used to refer to these individuals, despite the fact that many of them may actually be androids.

The Terminator, characters from the *Universal Soldier* film series, and the Daleks and Cybermen from *Doctor Who* are perhaps the

best-known examples of cyborgs in popular culture. Other notable cyborgs include Darth Vader, Lobot and General Grievous from *Star Wars*, the Borg from *Star Trek*, the replicants from *Blade Runner* and *Inspector Gadget*, and the Cylons from the 2004 *Battlestar Galactica* series. Other notable cyborgs include RoboCop, Evangelion, United States Air Force Colonel Steve Austin—both in the novel *Cyborg* and, as played by Lee Majors, in *The Six Million Dollar Man*—and the replicants from *Blade Runner*.

Characters originating in American comics include Deathlok and Victor ‘Cyborg’ Stone. Characters originating in manga and anime include 8 Man (who served as the basis for RoboCop), Kamen Rider, Rudol von Stroheim and Motoko Kusanagi from *Ghost in the Shell*.

Some examples of cyborgs found in video games include Kano, Jax, Cyrax and Sektor, all of whom are playable characters in the Mortal Kombat series. Both the Deus Ex video game series and the Syndicate video game series focus on the emergence of cyborgs in the near future and corporate control over these cyborgs.

One of the earliest depictions of a female cyborg can be found in William Gibson’s novel *Neuromancer*: Molly Millions, sometimes known as ‘Razorgirl’, has undergone extensive cybernetic modification and is widely regarded as one of the most iconic cyberpunk figures in the history of science fiction.

The cyborg was also a central feature of singer Janelle Monáe’s 48-minute video, released to accompany her 2018 album *Dirty Computer*. This visual narrative explored the relationship between humans and technology, showcasing the power of the digital in a future dystopian society.

Monáe has previously described herself as an android and portrayed herself as a mechanised creature who often adhered to idealistic principles, consequently using the cyborg as a means of breaking free from these authoritarian structures.

{End of Chapter 13}

Chapter 14: Neurotrophic Electrode

An intracortical device known as a neurotrophic electrode is used to read the electrical impulses that the brain employs during information processing. It consists of a small glass cone with a hollow interior, connected to a series of electrically conductive gold wires. The word ‘neurotrophic’ means ‘relating to the nourishment and maintenance of nerve tissue’, and the device takes its name from the fact that it is coated with Matrigel and nerve growth factor to promote the growth of neurites through its tip. The term ‘neurotrophic’ also means ‘relating to the nourishment and maintenance of nerve tissue’.

Locked-in syndrome leaves its sufferers with full cognitive function and awareness of their surroundings, but they are unable to move or speak due to almost complete paralysis of their voluntary muscles. The researchers initially used brain signals recorded via electroencephalography (EEG) to move a mouse pointer in their early efforts to give these patients some degree of control over their bodies

. The EEG, however, cannot compete with the speed and accuracy that can be achieved through the use of a direct brain-computer interface.

When Dr Kennedy began constructing the electrode, he was aware that he needed a device that could be implanted for an extended period, was physiologically compatible and could operate wirelessly. Initial research on rhesus macaques and rats showed that the neurotrophic electrode was suitable for chronic implantation over a period of up to 14 months (human studies would later demonstrate even greater robustness).

The hollow body and the pointed tip of the glass cone are coated with trophic elements to promote the growth of axons and dendrites across its surface. The glass cone is only 1–2 mm long. When the neurites reach the rear end of the glass cone, they re-attach to the neuropil located on that side. This serves to secure the glass cone in position. As a result, reliable and consistent recording over a longer period is achievable.

The interior of the glass cone is connected to three or four gold wires, which protrude from the rear of the cone. They are insulated with Teflon and record the electrical activity of the axons that has developed as they pass through the cone. As one end of the wires is implanted in the cortex and the other end is connected to amplifiers fixed to the inside of the skull, the wires are coiled to alleviate the strain that may be caused by their positioning. Differential signalling is provided by each amplifier via two wires connected to it.

As the neurotrophic electrode does not require transdermal wiring, one of its greatest advantages lies in its wireless capabilities. Consequently, the risk of developing an infection is drastically reduced. When neurological impulses are detected by the electrodes, they are sent through the skull and then on to the bioamplifiers after travelling up the gold cables (usually implemented by differential amplifiers). After amplification, the signals are transmitted via a switch to a transmitter, where they are converted into VHF signals before being emitted by an antenna

. An inductive signal at 1 MHz, which has been rectified and filtered, supplies power to the amplifiers and transmitters. All the necessary components, including the antenna, amplifiers, analogue switches and FM transmitter, are housed on a typical surface-mount printed circuit board positioned directly beneath the scalp. The entire device is coated with protective gels such as Parylene, Elvax and Silastikum, which are applied to make it biocompatible and to shield the electrical components from liquids.

The associated induction coil and an antenna, which are responsible for transmitting the FM signal to the receiver, are both located on the outside of the patient's head.

A water-soluble paste is used to temporarily secure these devices during installation. The signal is demodulated by the receiver and then sent to the computer so that spikes can be sorted and data recorded.

The vast majority of neurotrophic electrodes are manufactured by hand.

The gold wires were trimmed to the appropriate length, wound and then bent at a 45° angle just above the point of contact with the cone to limit the embedding depth.

At the point where the wires pass through the skull, an additional bend in the opposite direction is added. The Teflon coating that was previously on the tips was
removed, and those furthest from the cone
are the ones that are connected using a component joint and then sealed with dental acrylic.

The glass cone is made by first heating it and then sliding a glass rod onto one end. Once the required length has been reached, the tip is then cut off.

The other end does not have a clean finish; instead, it is cut at an angle to form a ledge onto which the gold wires can be mounted.

The wires are then laid out on the shelf and numerous layers of methyl methacrylate gel adhesive are applied over them, taking particular care to ensure that the conductive tips are not covered.

Finally, glutaraldehyde gas is used at a low temperature to carry out the sterilisation process on the device,

and ventilated.

Johnny Ray, one of Dr Kennedy's patients, was able to work out how to use the neurotrophic electrode to control a computer cursor. It was found that the movement of the pointer along the x-axis, the movement of the cursor along the y-axis and a 'selection function' were each linked to a unique brain signal transmitted by the device. An increase in the neuronal firing rate on the corresponding channel acted as a catalyst, causing movement in a specific direction.

It has been shown that neural signals extracted from one of Dr Kennedy's other patients can be used by a speech synthesiser to generate vowel sounds in real time. The electrical configuration was very similar to that used for the cursor; however, a post-receiver neural decoder and the synthesiser itself were incorporated into the setup. The researchers surgically implanted an electrode in the region of the motor cortex involved in the movement of speech articulators. This was done because a fMRI scan prior to the operation revealed strong activity

in this region when the patient was asked to name images. The typical time interval between brain activation and the synthesiser's output was fifty milliseconds, which roughly corresponds to the time taken via an unmodified biological pathway.

The electrode with neurotrophic properties is, as previously described, a device that operates wirelessly and transmits its signals transcutaneously.

Furthermore, it has a proven lifespan of more than four years in a human patient, as every component is fully compatible with living organisms.

Recent data from a prisoner who has had the device implanted for 13 years clearly show no scarring and numerous myelinated nerve filaments (axons)[12] Many emerging types of electrodes, including those currently being researched by Neuralink, still suffer from the same difficulties.

However, data from metal electrodes are highly advantageous in the short term and have generated a large amount of data that is very valuable in the field of brain computing.

The neurotrophic electrode, however, was limited in the amount of information it could provide. This was due to the fact that the electronics used to transmit the signal took up so much space on the head, and a human skull could accommodate a maximum of four such devices. This was the first research to demonstrate that LFPs could be used to control a device.

Electroencephalography, often known as an EEG, requires the implantation of a significant number of surface electrodes on the patient's head and is an attempt to monitor the activity contributed by tens of thousands to millions of neurons.

The electroencephalogram has the potential to be used as a brain-computer interface in the long term, as the electrodes do not need to be removed from the scalp at any point.

The EEG has always lagged behind similar intracortical devices in terms of temporal resolution, spatial resolution and signal-to-noise ratio, but has the advantage of not requiring surgical intervention.

Their published data suggest a loss of signal within two years [14].

As the axons must grow into the cone before the device can detect electrical impulses, the neurotrophic electrode is not active immediately after implantation. According to the results of many studies, the tissue development process is usually complete within one month of treatment; however, it can take up to four months for the growth to stabilise. Given the life expectancy of the patient, who hopes to move or speak again, a waiting period of four months does not represent a significant disadvantage.

The risks associated with implantation are similar to those often associated with brain surgery. These risks include haemorrhage, infection, seizures, strokes and brain damage. The treatment is only carried out in very rare or experimental circumstances until technological advances enable a significant reduction in the associated risks.

After becoming embedded in the neuropil, one of the neurotrophic electrodes began to produce an inconsistent signal following its implantation in Johnny Ray in 1998.

As a result, Dr Kennedy was forced to rely on the other devices to manage Johnny Ray's condition. This was NOT due to a problem with the electrode, but rather with the circuitry.

Since November 2010, Dr Kennedy has been working on the application of the electrode relating to speech synthesis. However, he has plans to extend its use to many different areas, one of which is the restoration of mobility using neuroprostheses.

'Speech processing in the absence of an audible auditory signal' is referred to as 'silent speech', and its main purpose is to help those who are confined.

Silent speech has been successfully decoded ([12]).

A secondary aim is to use speech, whether audible or silent, as a "mobile phone beneath the skull, with electrodes accessing the motor cortex responsible for speech". This means that speech can be recorded either audibly or silently.

as a retail product.

Information from Phil Kennedy: It is possible that the reader may recoil at such a concept.

But let me make this clear.

Consider all the benefits that come with owning a personal mobile phone that is permanently implanted in your body.

To say: ‘I need to get in touch with so-and-so, I need to ask Siri a question, I need to connect to the cloud to get some information, I need access to the cloud to carry out a calculation, I need to use the internet for work, it’s important that I keep track of how my investments are performing; it’s essential that you tell me where your children are; I need someone to call the emergency services as I’ve just been injured; and so on.

I can send them a text message or ring them without thinking, without having to find my phone and tap on it. The mobile phone under the scalp will bypass this step.

It will establish constant contact at the user’s discretion and can be deactivated if the user so wishes.

Furthermore, it is important to bear in mind that previous research has shown that people do not shy away from using technologies that are imperceptible to them, i.e. those implanted beneath the surface of the skin or the scalp.

Take, for example, the way in which pacemakers were initially rejected because they were cumbersome and had to be worn outside the body.

They are now fully implanted and are routinely recommended to patients.

As I see it, this unsettling turn of events is also quite inevitable.

Therefore, my prediction is that, having helped people who are struggling, we will ultimately benefit humanity by providing them with a consumer product. In the same way, if those who are struggling financially are the dog's tail and humanity as a whole is the dog, then in the end the tail will wag the dog, rather than the dog wagging the tail!

{End of Chapter 14}

Chapter 15: Hippocampal Prosthesis

One type of cognitive prosthesis is known as a hippocampal prosthesis (a prosthesis implanted into the nervous system to enhance or replace the function of damaged brain tissue). The normal function of a damaged body part can be restored with the aid of prostheses. This restoration may consist of a simple structural replacement (such as reconstructive surgery or a glass eye), or it may be a more fundamental, functional restoration (e.g. a peg leg or a hook). Nevertheless, prostheses that involve the brain fall into several different categories and must adhere to certain limitations. ‘Input’ prostheses, such as retinal or cochlear implants, send impulses to the brain, which the patient gradually learns to interpret as sight or hearing. Examples of such prostheses include hearing aids and artificial limbs. ‘Output’ prostheses require extensive training, during which the patient learns to generate the required action through their thoughts. These prostheses use the patient’s brain signals to control a bionic arm, a hand or a computer device. Both types of prosthesis rely on the brain’s ability to adapt to

meet the requirements of the prosthesis, enabling the user to ‘learn’ how to use their new body part. A cognitive prosthesis, often referred to as a ‘brain-to-brain’
prosthesis, does not use trained input or output signals, but rather the natural signals normally used by the region of the brain that is being replaced (or assisted). Therefore, a device of this kind must be capable of fully replacing the function of a modest part of the nervous system whilst maintaining the normal functioning of that part. Developers must have a comprehensive understanding of how the nervous system works in order to achieve this goal. To manufacture and install a cognitive prosthesis appropriately, the scope of the design must encompass not only the technology but also a reliable mathematical model. The primary aim of developing an artificial hippocampus is the successful treatment of Alzheimer’s disease and other conditions associated with the hippocampus. To achieve this, the artificial hippocampus must be capable of receiving information directly from the brain, processing this information and providing an appropriate output to the cerebral cortex; in

other words, it must function exactly like a normal hippocampus. Furthermore, the artificial organ must be entirely self-sufficient, as the presence of an external power source significantly increases the likelihood of infection.

The human limbic system generates emotions through its interaction with the neocortex and other regions of the brain, including the hippocampus, which is a component of the limbic system. Long-term memories of familiar faces are stored in the hippocampus, which is responsible for their formation. To put it another way, this is the region of the brain responsible for our ability to associate a name with a particular face. Alzheimer's disease is strongly associated with damage to the hippocampus, due to the close link this part of the brain has with the process of memory formation.

The hippocampus is a structure located on both sides of the brain, directly beneath the neocortex. 'Comprising several different subsystems that form a closed feedback loop', the hippocampus 'comprises several different subsystems that form a closed feedback loop', with input from the neocortex entering via the

entorhinal cortex, propagates through the intrinsic subregions of the hippocampus, and returns to the neocortex. Viewed through the lens of electronics, the hippocampus is analogous to a sheet of parallel circuits.

As the prosthesis is surgically implanted in the patient's brain for the rest of their life, it must be biocompatible in the long term. Furthermore, we must take into account the tendency for brain cells such as astrocytes to envelop the implant. (This is a normal response by brain cells to protect neurons), which results in the brain cell's function being impaired.

To be considered biomimetic, an implant must be capable of mimicking the functions and properties of natural biological neurons. To achieve this, we need a comprehensive understanding of how the brain works so that we can construct a robust mathematical model upon which to build. The discipline of computational neuroscience has made significant progress in this endeavour.

To begin with, we must bear in mind that the activities of neurons, much like most biological processes, are extremely non-linear and depend on a multitude of parameters, such as

input frequency patterns and so on. A decent model must also take into account the fact that the activity of a single neuron plays only a minor role in the processes taking place, as these processes are carried out by groups of neurons interacting within a network. Once implanted, the device must take over the role of the damaged hippocampus for an extended period and fulfil all its functions, or at least the majority of them. First and foremost, artificial neurons must be capable of cooperating within networks in the same way as real neurons. They must then be able to establish synaptic connections with the neurons already present in the brain that are both functional and efficient; consequently, a model for an interface between silicon and neurons will be required.

The implant must be small enough to be implanted, whilst at the same time being designed to minimise the extent of collateral damage occurring during and after the procedure.

In order for the prosthesis to fully take over the function of the damaged hippocampus, it must be capable of connecting in

connect with the healthy tissue surrounding it in both directions. In other words, the implant must be capable of receiving information from the brain and providing relevant and comprehensible input to the surrounding nerve cells.

Given that every person's brain has unique structural and functional characteristics, it is essential that each neural implant is tailored to the recipient. This requires the development of a precise model of the hippocampus, as well as the use of state-of-the-art brain imaging techniques to identify individual differences.

Given that the prosthesis is implanted into the patient's brain, the procedure itself will be very similar to that of tumour removal surgery. Although there will be an unavoidable degree of collateral damage, the impact on the patient will be fairly minor.

"To begin developing a prosthesis that integrates the non-linear dynamics of real neurons into neural models, it is first necessary to carry out precise measurements of biological neurons. Using the concepts of non-linear

systems theory, we were able to devise and apply techniques for measuring the non-linear dynamics of hippocampal neurons (Berger et al., 1988a,b, 1991, 1992, 1994; Dalal et al., 1997). These approaches were published in Berger et al., 1988a,b, 1991, 1992 and 1994. (Lee and Schetzen, 1965; Krausz, 1975; P. Z. Marmarelis and Marmarelis, 1978; Rugh, 1981; Sclabassi et al., 1988). A random sequence of electrical pulses is used as the input in this method, and electrophysiological recordings of the evoked output of the target neuron are made whilst the neuron is being stimulated. This enables an experimental assessment of the properties of neurons (Figure 12.2A). Inter-pulse intervals vary according to a Poisson process with a mean of 500 milliseconds and a range of 0.2–5000 milliseconds; the input train consists of a sequence of pulses (up to 4064), and the mean of these intervals is 500 milliseconds. Consequently, the input is ‘broadband’ and stimulates the neuron across the majority of its operating range. In other words, the statistical properties of the random train are extremely consistent with the known physiological properties of hippocampal neurons. The kernels of a functional power series are

used to model the non-linear response characteristics, which are expressed in terms of the relationship between progressively higher-order temporal properties of a sequence of input events and the probability of the neural output. These characteristics are expressed in the form of the non-linear response."

Technologies such as electroencephalography, magnetoencephalography, functional magnetic resonance imaging and other types of imaging technologies are essential for the implantation of the device, which requires a high degree of precision to minimise collateral damage (as the hippocampus is located within the cortex) and to ensure the effective operation of the device.

A silicon-neuron interface will be necessary to facilitate correct interaction between the brain’s biological neurons and the prosthesis’s silicon neurons.

In the brain, tasks are not performed by a single cell, but by groups of interconnected neural networks. For this reason, any prosthesis must be capable of mimicking the behaviour of a

network. Consequently, a high-density hippocampal neuron network processor is required so that the prosthesis can assume the role of a biological hippocampus. To achieve this, we need a large number and high density of silicon neurons to create an effective prosthesis. A neuron-silicon interface is also required to enable the implanted prosthesis to communicate in both directions. In addition to ensuring the density and uniqueness of the connections, the choice of material and the design must guarantee the long-term survival of the system as well as its biocompatibility.

Providing sufficient power for each brain implant remains a major challenge. As the prosthesis is implanted in the brain, the power source must meet a wide range of requirements and be biocompatible in the long term. Firstly, the power source must be capable of recharging itself. As the brain is so sensitive, infection is a far greater problem with neural implants than with other types of prostheses. Consequently, an external power source is not even an option for these devices. As the brain is also highly sensitive to heat, neither the power source nor the

device itself must not generate excessive heat, in order to prevent disruption to normal brain function.

A prosthetic device, the Neuronal Memory Silicon Chip, is a piece of technology that mimics the way in which long-term memories are formed in the human brain. Theodore Berger, a biomedical engineer and neurologist working at the University of Southern California, was the one who developed the concept for the device's prototype. In the early 1990s, Berger began work on the device's architecture. He collaborated with other researchers who were able to implant electrodes into animals such as rats and monkeys to assess whether memory function could be restored. Recent research has shown that the system is capable of forming long-term memories across a variety of behavioural contexts. Berger and his colleagues have the long-term aim of using these chips in future as electronic implants for human patients suffering from neurodegenerative diseases such as Alzheimer's, which lead to disruptions in neural networks.

Berger and his colleague Vasilis Marmarelis, a biomedical engineer at the University of Southern California, worked with

hippocampal slices from rats to initiate the process of creating a brain prosthesis. The researchers knew that neural signals travel from one side of the hippocampus to the other, so they injected random pulses into the hippocampus, recorded the signals at specific points to see how they were altered, and then devised equations that reflected the changes they observed. They went on to programme these calculations onto the computer chips.

The next step for the scientists was to determine whether a chip, often referred to as an implant, could be used as a prosthesis for a damaged area in the hippocampus. To do this, they needed to establish whether or not it was possible to bypass a significant part of the circuitry in the brain slices. They implanted electrodes at the site that sent electrical impulses to a chip located outside the body. The chip then carried out the processes typically performed in the hippocampus, whilst additional electrodes sent the signals back to the brain slice under investigation.

In 1996, Dr Sam A. Deadwyler of Wake Forest Baptist Medical Centre in Winston-Salem, North Carolina, investigated the activity patterns of clusters of hippocampal neurons. The research was carried out whilst rats were performing a task that required them to use their short-term memory.

These ‘ensembles’ or clusters of neurons fired in a variety of patterns, both over time and across ‘space’ (where ‘space’ refers to the many neurons distributed throughout the hippocampus), depending on the type of behaviour required for the task. Most importantly, Deadwyler and his colleagues were able to identify patterns that clearly distinguished between the numerous stimuli that formed part of the task. These patterns included location (which is analogous to place cells), behavioural responses and which part of the task was taking place. Analyses based solely on the activity of the neural ensemble, without taking any of the above factors into account, are capable of recognising some of these variables and even predicting them before they occur. Following the discovery of the memory codes in the hippocampus, Deadwyler worked with Berger on forthcoming research in which Berger’s team would develop models of

memory function in the hippocampus, whilst Deadwyler's team would test the models on rats and monkeys and eventually move on to human trials. Berger's discovery of memory codes in the hippocampus prompted Deadwyler to collaborate with Berger.

Berger collaborated with Deadwyler and Dr Robert E. Hampson of Wake Forest University to test a prototype of the memory prosthesis by connecting it via electrodes to the brains of rats and monkeys, enabling it to process information in the same way as the real hippocampus. This was done to prepare for tests on awake, behaving animals. Even rats with a destroyed hippocampus were able to form new memories with the aid of the prosthetic model. By administering drugs to the rats, Deadwyler and Hampson were able to inhibit the animals' ability to acquire long-term memories during one of the experiments. This disrupted the neural circuits that normally transmit signals between two subregions of the hippocampus. The formation of long-term memories depends on the interaction between the CA1 and CA3 subregions. The rats were unable to remember

which lever they had to pull to claim their reward. The researchers then developed an artificial hippocampus capable of replicating the pattern of CA3–CA1 interactions. To do this, they first used an electrode array to analyse the neural spikes generated by the cells, and then used the same array to reproduce the same pattern. When the rats' hippocampi were stimulated using a mathematical model of the prosthesis, the rats showed a significant improvement in their ability to determine which lever to pull. This artificial hippocampus played a significant role in the development of a memory prosthesis, as it demonstrated that, when a prosthesis and its associated electrodes were implanted in animals with a defective hippocampus, the device might be able to restore memory capacity to that of normal rats. This artificial hippocampus also played a significant role in the development of a memory prosthesis.

The research teams at USC and Wake Forest are seeking to make this technology available to people whose

have suffered brain damage as a result of Alzheimer’s disease, a stroke or an injury. Disruption to neural networks often prevents the formation of long-term memories. The signal processing that would normally take place in neurons that have not been destroyed can now occur thanks to the method developed by Berger and implemented by Deadwyler and Hampson. Their ultimate aim is to restore the ability to form memories that are stored for a longer period by implanting chips such as this one into the brain.

In 2004, Theodore Berger and his colleagues at the University of Southern California in Los Angeles developed a hippocampal prosthesis that proved successful in in vitro tests on slices of human brain tissue.

In 2018, a team from Wake Forest Baptist Medical Centre led by Robert E. Hampson – which also included Berger and Deadwyler – was the first to demonstrate the effectiveness of the prosthetic model in actual patients. As part of a medical diagnostic procedure for epilepsy carried out at Wake Forest, electrodes were surgically implanted into the brains of the study participants. Patients who had

had electrodes implanted in their hippocampi agreed to undertake a memory exercise on a computer whilst their hippocampal neural activity was being recorded. This enabled Berger and his colleagues at USC to personalise the hippocampal prosthesis model for each individual patient. Using their model, the Wake Forest researchers were able to demonstrate an increase in memory function of up to 37 per cent in individuals whose condition had led to impaired memory. It was shown that memory performance improved for up to seventy-five minutes following stimulation by the hippocampal prosthesis model. Since 2018, research has been conducted to test memory codes against more characteristics and aspects of objects that need to be recalled, in addition to the duration of memory enhancement, which extends beyond 24 hours.

{End of Chapter 15}

Chapter 16: Brain Technology

Brain technology, or knowledge systems capable of independent learning, is one way of defining a technology that utilises the latest discoveries in neurobiology.

[see also Neuroimplants] The Laboratory for Artificial Intelligence in Zurich is credited with first proposing the term ‘Schweiz’, which refers specifically to the Roboy project.

as well as any other programme capable of teaching itself.

In particular, applications of brain technology enable the visualisation of the underlying learning architecture, often referred to as ‘know-how maps’.

The use of non-invasively recorded electroencephalogram (EEG) signals from a human subject to operate a slide projector was one of the earliest demonstrations of BC in humans and animals and took place in the 1960s. Grey Walter was the person who carried out this demonstration (Graimann et al., 2010).

Shortly after Jaceques J. Vidal first introduced the concept, it came to be known as a ‘brain-computer interface’ (BCI). Brain-computer interfaces are capable of detecting brain activity, transmitting the information outside the body, processing the data using algorithms, and converting the signals into command and control signals.

In a groundbreaking study published in *Nature* in 2012, two patients with tetraplegia were connected to the BrainGate neural interface system, demonstrating that they could operate robotic arms through thought. The work was led by a pioneer named Leigh Hochberg, MD, PhD. Both participants were able to reach for and grasp objects located in three-dimensional space, and one of the participants used the system to pour herself a cup of coffee for the first time since her paralysis nearly 15 years earlier.

And in October 2020, two patients were able to send text messages using an operating system that could be controlled wirelessly, send emails, and, in a study led by Thomas Oxley, the participants were able to shop and

carry out banking transactions whilst connected to the Stentrode brain-computer interface (Journal of NeuroInterventional Surgery).

This was the first time that a brain-computer interface had been implanted via the patient's blood vessels, thereby eliminating the need for open-brain surgery.

A number of research organisations are now investigating a variety of experimental devices that use brain-computer interfaces, which have the potential to radically transform the way people with paralysis and a range of other neurological conditions live their lives.

These include: Elon Musk, Facebook, amongst others, as well as the University of California, San Francisco.

The various systems using this technology are also being investigated as potential neuromodulation devices and may one day help in the diagnosis and treatment of a wide range of conditions affecting the brain, such as epilepsy and Parkinson's disease

{End of Chapter 16}

Chapter 17: Stent-Electrode Recording Array

Without the need for open brain surgery, a stentrode (stent-electrode recording array) is a tiny array of electrodes that is permanently implanted into a blood vessel in the brain and placed on a stent. The two patients were able to control an operating system wirelessly to send text messages, emails, make purchases and carry out banking transactions by thinking directly via the stentrode brain-computer interface; this was the first time a brain-computer interface had been implanted via the patient's blood vessels, thereby eliminating the need for open brain surgery. It is currently undergoing clinical trials as a brain-computer interface (BCI) for people who are paralysed or have lost limbs.

In August 2020, the device was granted breakthrough status by the FDA.

In 2010, Oxley began developing the implant through Synchron, the company he founded himself. Once captured, the signals are sent to a wireless antenna device implanted in the chest. This device then transmits the

signals to an external receiver. The patient would need to learn how to use an operating system on a computer connected to assistive devices.

Stentrode technology has been evaluated in both sheep and humans, and in November 2018, the Human Research Ethics Committee at St Vincent's Hospital in Melbourne, Australia, granted approval for the use of the technology in human trials.

{End of Chapter 17}

Chapter 18: Chronic Electrode Implant

An electronic device that is implanted chronically (over a prolonged period) into the brain or other electrically excitable tissue is referred to as a chronic electrode implant. It is possible either to record the electrical impulses occurring in the brain or to stimulate neurons with electrical impulses originating from an external source.

The possibility that brain-computer interface technology might one day be able to restore lost sensory or motor functions is astonishing; those who have become paralysed as a result of damage to their peripheral nerves may be able to make a full recovery if their motor cortex activity is recorded directly, but the technology is still in its infancy and unreliable. [1][2] There are numerous examples in the literature of intracortical electrode recording being used for a variety of purposes, which fail after a few weeks or, at best, a few months. [3][4][5][6][7][8][9][10] This paper will review the current state of research into

electrode failure and will place greater emphasis on recording electrodes than on stimulating ones.

There are two distinct types of chronic brain-computer interfaces: stimulating and recording. An example of the use of stimulating interfaces is
in sensory prostheses, such as cochlear implants,
which are the most effective type of sensory prosthesis), as well as deep brain stimulation treatments, whilst recording interfaces can be used for research applications[11] and to record the activity of speech or motor centres directly from the brain.

In theory, these devices could fail due to the same tissue reaction that is responsible for the failure of implanted electrodes. Increasing the signal intensity, on the other hand, enables stimulating interfaces to circumvent this problem.

Recording electrodes, however, must rely on the signals already present in the area where they have been implanted and cannot be made more sensitive with minimal effort.

The implanted microelectrodes currently available are unable to reliably record single-unit or multi-unit activity on a chronic basis. In their 2006 review, Lebedev and Nicolelis highlight the particular need for further research in this field to bring the technology to a level where it can be used clinically. In summary, the four conditions set out in their review are as follows:

1) Continuous recording over an extended period (spanning years) of vast neuronal populations located across many regions of the brain; 2) The effective use of computing resources to process the collected data; 3) The incorporation of feedback into the user's body image using native plasticity; 4) Advances in prosthetic technology to create artificial limbs that are
are capable of reproducing the full range of motion. [12][13]

This study focuses on strategies that have been investigated in the literature and are relevant to the aim of obtaining consistent recordings over an extended period. Research conducted with the intention of achieving this aim

can be divided into two basic categories: identifying the specific causes of recording errors and developing strategies to prevent or delay electrode failure.

As indicated above, if significant progress is to be made towards implanted electrodes that can be used in the long term, then documenting the response of living tissue to electrode implantation, in both the acute and chronic timeframes, is a critical step that must be taken.

It is ultimately this tissue reaction that causes electrodes to fail by encapsulating the electrode itself in a protective layer known as a ‘glial scar’ (see 2.2).

The lack of true uniformity in the implantation procedure or the electrode materials is a significant obstacle to a complete understanding of the tissue’s response.

Silicon is a material frequently used in the manufacture of electrodes and probes, alongside platinum, iridium, polyimide, ceramics, gold and others. [[14][15][16][17][18][19][20] In addition to the

variety of materials used, electrodes are constructed in many different forms, [21] including planar shafts, straight and homogeneous micro-wires, and probes that have a wider base and taper gradually to a point.

Research involving implantable electrodes also utilises a variety of surgical procedures for electrode implantation; the most critical differences relate to whether the implant is anchored above the skull or not [22]and the speed of insertion. [23] The overall tissue reaction observed is caused by a combination of the traumatic injury resulting from electrode insertion and the prolonged presence of a foreign body within the nervous tissue.

The insertion of the electrodes into the tissue is the immediate source of damage that may be caused by their use.

Consequently, research into minimising the size of the electrode and the appropriate insertion technique is a key focus here.

Short-term effects of electrode insertion on the surrounding tissue have been extensively documented. [24] These

include cell death (both neuronal and glial), neuronal processes and blood vessels that have been severely damaged, mechanical tissue compression, and the accumulation of waste products caused by cell death.

In the study by Bjornsson et al.

A 2006 study developed and utilised an in vitro model specifically designed to investigate the distortion and injury of brain tissue caused by electrode implantation.

Electrodes were fabricated from silicon wafers to have three different sharpnesses (inner angle of 5° for sharp, 90
° for medium, 150° for blunt).

In addition, insertion was performed at three different rates: 2 mm/s, 0.5 mm/s and 0.125 mm/s.

Real-time images of electrodes inserted into coronal brain sections 500 μm thick were used to provide qualitative assessments of damage to the blood vessels.

To enable direct imaging of vascular deformation, the tissue was labelled with fluorescent dextran and microspheres prior to examination.

The blood vessels were completely saturated with the fluorescent dextran, allowing the underlying geometry to be observed alongside any distortions or ruptures that may have occurred.

Microspheres that fluoresced in the visible spectrum were embedded throughout the tissue and provided discrete coordinates that were used by a computer to perform calculations on strain and deformation.

Analysis of the photographs led to the classification of the damaged tissue into one of four types:

1) fluid displacement, 2) vessel rupture, 3) vessel transection, and 4) vessel dragging.

The displacement of fluid caused by the insertion of the device almost always resulted in ruptured vessels. Severing and dragging were observed continuously along the entire insertion path; however, there was no correlation between these two phenomena and the tip shape. Instead, it was shown that these features correlated with the insertion speed, with a higher prevalence at moderate and slow insertion rates. The only

scenario in which no vascular injury was observed was one in which the probes were inserted more rapidly and were sharper.

Following prolonged placement in brain tissue, microelectrodes cause something akin to a foreign body reaction in the body; microglia and astrocytes are the primary cell types responsible for this response.

Each type of cell plays several roles in maintaining a healthy body and undamaged neural tissue, and each is also ‘activated’ by injury-related mechanisms, leading to changes in morphology, expression profile and function.

It has also been shown that the tissue reaction is greater in situations where the electrodes are anchored through the subject’s skull. The anchoring forces exacerbate the injury caused by the insertion of the electrode and sustain the tissue reaction. [25]

When microglia are activated, they perform a range of functions, one of which is the accumulation of foreign substances and the enzymatic degradation of these substances.

According to one theory (which has been put forward), if the foreign body cannot be broken down – as is the case with implanted electrodes whose material composition is resistant to the enzymatic degradation described above – this ‘frustrated phagocytosis’ contributes to the failure of the recordings, releases necrotic substances into the immediate vicinity and contributes to cell death around the electrode. [26]

The majority of the encapsulating tissue that develops around implanted electrodes consists of activated astrocytes. “Current theories assume that glial encapsulation, i.e.

gliosis, protects the electrode from the influence of neighbouring neurons. Consequently, this reduces the diffusion rate and increases impedance, increases the distance separating the electrode from the neurons closest to it, or creates an environment that inhibits the expansion of neurites, thereby repelling regenerating neuronal processes away from the recording sites”. [(27)] [28] Either activated astrocytes or the accumulation of cellular debris resulting from cell death around the electrode would isolate the recording sites from other, active neurons. [29] Even very slight increases in the separation between the electrode and the local neuronal population can

completely, as the electrodes must be within 100 µm to receive a signal.

Another recent study addresses the issue of the tissue response. [30] Michigan electrodes (see article for detailed dimensions) were surgically implanted into the brains of adult male Fischer 344 rats; A control group was also subjected to the same surgical procedures; however, the electrode was inserted into the patients and then withdrawn very shortly afterwards, so that a contrast could be established between the tissue's reaction to acute damage and its reaction to chronic presence.

The animals were euthanised two weeks and four weeks after implantation, so that histological and immunostaining methods could be used to assess the tissue response.

The presence of ED1 and GFAP was determined by staining the samples.

Findings positive for ED1 indicate the presence of macrophages and were observed in a densely packed area within approximately 50 µm of the electrode surface.

Two and four weeks after implantation, there was evidence of the presence of ED1+ cells, with no discernible change observed across the different time points.

It is possible to infer the presence of reactive astrocytes from the presence of GFAP, and evidence of this was observed two and four weeks after implantation, extending more than 500 μm from the electrode surface.

The controls, which received a stab wound, showed signs of inflammation as well as reactive gliosis; however, the signal strength was noticeably lower than in the chronic test subjects and improved significantly after four weeks compared with two weeks.

This provides compelling evidence that glial scarring and encapsulation play a role in both delayed microelectrode implantation and delayed microelectrode implantation, and are ultimately the main cause of the adverse effects of implanted microelectrodes, as opposed to the more severe acute damage.

In another recent study investigating the effects of chronically implanted electrodes, researchers found that the nerve tissue appeared to have a lower sensitivity

to tungsten-coated electrodes, which triggered a limited and localised inflammatory response confined to the area immediately surrounding the implant, associated with minor cell death [31].

It seems reasonable that strategies to prevent long-term electrode failure should focus on neutralising the foreign body reaction.

Increasing the biocompatibility of the electrode itself is the most obvious way to achieve this, and it is a readily attainable goal, thereby reducing the tissue's perception of the electrode as a foreign substance.

Consequently, a significant proportion of the research being carried out to reduce the tissue reaction focuses on improving biocompatibility.

Given the many different lines of inquiry being pursued in this field of study, it can be difficult to make an accurate assessment of the progress made towards improving the biocompatibility of electrodes.

This section provides a general classification of the many strategies described in the research literature for increasing biocompatibility. The descriptions of the studies are limited

to providing only a concise explanation of the theory and methodology; the results, on the other hand, are described in detail in the original articles. To date, no method has produced results that are comprehensive and far-reaching enough to modify the fundamental nature of the encapsulation reaction.

On silicon-based electrodes, the majority of research into bioactive coatings is carried out with the aim of reducing the tissue response. Examples of techniques are given below:

Encapsulation of the anti-inflammatory neuropeptide α-MSH beneath a layer of nitrocellulose or within a nitrocellulose matrix, which is gradually released into the local tissue following implantation; [32]

A laminin and polyethylenimine (PEI) coating was applied to the electrodes in alternating layers (LN), with the aim of the outer LN layer reducing the tissue reaction by helping to camouflage the electrode as native material; [(33][34)]

Increasing the electrical conductivity of electrodes by covering them with a layer of conductive polymer, thereby overcoming

the encapsulation barrier by increasing electrode sensitivity. [35]

The functionalisation of the electrode surface with the appropriate protein sequences is the subject of a further study, which is being conducted with the aim of increasing the biocompatibility of electrodes.

Studies have shown that surfaces functionalised with sequences of adhesive peptides reduce cellular motility and support higher neuronal populations. [36][37] It has also been shown that peptides can be selected to specifically promote neuronal or glial growth, and that peptides can be deposited in patterns to control cellular outgrowth. [38][39][40] If populations of neurons can be induced to grow onto implanted electrodes, electrode failure should be minimised as far as possible.

Kennedy's research describes the use of a glass cone electrode containing an embedded micro-wire.

[41] The micro-wire is used for recording; furthermore, the cone is filled with neurotrophic chemicals or nerve tissue to promote the development of local neurons into the

electrode, which is necessary for the recording to take place.

This strategy circumvents the problem of tissue reaction by inducing neuronal growth closer to the recording surface.

Some notable successes have also been achieved in the development of microfluidic delivery mechanisms, which are said to be capable of delivering targeted pharmacological agents to electrode implantation sites in order to mitigate the tissue reaction. [42]

The creation of standardised research tools requires considerable effort, similar to that invested in the advancement of other fields. To enhance the reliability of the technology, the purpose of these tools is to provide a robust and unbiased method for assessing the failure of chronic brain electrodes.

One such endeavour involves the development of an in vitro model to investigate the phenomena of tissue reaction. This involves the surgical removal of the midbrain from Fischer 344 rats, which are then cultured to produce a confluent layer

of neurons, is carried out on day 14 of the experiment, along with microglia and astrocytes.

This confluent layer can be used to investigate the foreign body reaction to scratch injuries, or electrode micro-wires can be deposited onto the monolayer and examined using this method, whereby the culture is fixed at defined time points following insertion/injury and the tissue reaction is examined using histological methods.
[43]

A numerical model of the mechanical electrode–tissue interaction is another research technique that can be utilised.

The purpose of this model is not to provide specific information about the electrical or chemical properties of the interface, but rather the mechanical properties resulting from the attachment of electrodes to tissue, the bonding forces and any discrepancy in strains.

This model can be used to predict forces generated at the interface by electrodes of different material stiffnesses or geometries. [44]

For research requiring a large number of similar electrodes, a method that can be carried out on a workbench, using a silicon mould as a master to produce numerous copies from polymeric materials via a PDMS intermediate, has been demonstrated in published research.

This is extremely useful for materials studies or for laboratories that require a large volume of electrodes but cannot afford to purchase them all. [45]

{End of Chapter 18}

Chapter 19: Cortical Implant

A subcategory of neuroprosthetics known as a cortical implant is one that establishes a direct connection with the cerebral cortex of the brain. Depending on its design and location, the cortical implant can provide stimulation to an immediate area and offer significant benefits, as it is directly connected to various sections of the brain. This enables the implant to deliver both stimulation and various benefits. An implanted microelectrode array is a common type of cortical implant. This is a tiny device that can either receive or transmit brain signals and is used to stimulate the cortex.

‘Replacing neural circuits in the brain that no longer function adequately’ is the overarching aim of a cortical implant, as well as of neuroprosthetics in general.

Patients who are blind may be able to regain their sight with the help of cortical implants. Patients suffering from dementia could also benefit from these implants. Due to the complexity of the brain, the potential for these brain implants to enhance their

capabilities are virtually limitless. Stimulation of the visual cortex was one of the earliest areas of focus in the field of cortical implants and was carried out using silicone rubber implants. However, due to the micro-movements that occur within the brain, a certain degree of flexibility is required to prevent damage to brain tissue.

Through direct stimulation of the visual cortex, various types of cortical implants are capable of partially restoring a patient's vision.

Very little progress has been made in developing an effective hearing aid that is directly connected to the auditory cortex. However, there are some devices, such as an auditory brainstem implant and a cochlear implant, which have successfully restored hearing in patients who were previously deaf. There have also been several studies using microelectrode arrays to collect measurements from the auditory cortex in animals. These studies have been carried out across a wide range of species. A study involving rats was conducted to develop an implant capable of enabling simultaneous measurements from the thalamus and the auditory cortex. The quality of the

measurements generated by this novel microelectrode array was comparable to that of other widely available devices, although these other devices did not provide simultaneous measurements. Studies such as these pave the way for improvements that could lead to the development of new hearing aids.

A range of different cortical implants has been developed with the aim of enhancing cognitive performance. The prefrontal cortex or the hippocampus are the target areas for the implantation of these devices. By replicating the mini-columnar arrangement of neural firing, implants in the prefrontal cortex restore attention, decision-making and motor selection.

The term ‘brain-computer interface’ (BCI) refers to a specific type of implant that enables a direct connection between a patient’s brain and some form of external hardware. Since the mid-1990s, the volume of research being conducted on BCIs using animal and human models has increased exponentially. The vast majority of brain-computer interfaces are used to extract neural signals in some way

, whilst others aim to restore sensation via an implanted signal. Creating a tactile response for a prosthesis is a good example of how the restoration of sensation can be achieved through the use of an implanted signal. Amputees have no tactile response in their prostheses; nevertheless, an implant in their somatosensory cortex may one day be able to provide them with an artificial sense of touch.

BrainGate, developed by Cyberkinetics, is an example of a brain-computer interface that is now available on the market. Since May 2009, this BCI has been undergoing a second round of clinical trials. In an earlier experiment, one of the participants was a patient who had suffered a severe spinal cord injury and lost control of all his limbs. He achieved his goal of controlling a computer mouse using only his mind. Further improvements have been made, enabling more complex interactions, such as controlling a robotic arm.

The direct interface with the cortex is one of the main advantages that cortical implants have over other types of

neuroprostheses, and is probably one of the most significant. The ability to treat a wider variety of patients is made possible by bypassing the damaged tissue in the visual pathway. These implants are also capable of acting as a replacement for damaged tissue in the cortex. The use of the biomimicry concept enables the implant to function as an alternative channel for signals.

There are potential complications associated with any type of implant that is directly connected to the cortex.

Biocompatibility, often referred to as the body's reaction to the introduction of a foreign body, is a key concern with cortical implants. If the patient's body does not accept the implant, the patient will experience more problems as a result of the implant than fewer. In addition to the implant needing to be biocompatible, there is also the possibility that the body may have an adverse reaction to it after it has been in place for a prolonged period, rendering the implant ineffective. It has been shown that implants can also induce neurodegeneration at the site where they are implanted.

The challenge of neural coding is one that cortical implants – and in particular those concerned with cognition

. Researchers have struggled to unravel the mystery of how the human brain stores individual memories. For example, the way the brain encodes the memory of a chair is quite different from the way it encodes the memory of a light. Once we have fully understood the neural code, we will be able to make greater progress in creating a hippocampal prosthesis that enhances memory function more successfully.

It is difficult to standardise methods that require direct implantation, as each patient’s cortex is unique. This makes it impossible to compare the results across different patients. Whilst there are numerous physical characteristics common to all brains, the neuroanatomy of a specific gyrus or sulcus can vary from brain to brain when examined side by side. This leads to problems, as each method is different, which in turn means it takes longer to complete. Furthermore, the shape of the stimulus to be generated by a microelectrode array is limited due to the aforementioned variations, which, when combined with the individual uniqueness of the cortex—also

‘differences’. The physical size and potential data processing/capacity rates of today’s microelectrode arrays are also limiting factors. These factors remain constrained in relation to the characteristics required in accordance with Moore’s Law.

Further research is being conducted, which will lead to new advances that will enhance the viability and utility of cortical implants. The size of the implants can be reduced, as can the complexity of the surgical procedures required to place them, as the implants are made smaller. As new innovations are developed, lifespan is another factor taken into account for these devices. The development of new implants is about “preventing, or at least minimising, hydrolytic, oxidative and enzymatic degradation caused by the harsh environment of the human body, enabling the interface to function over a long period before it eventually needs to be replaced”. This objective can be expressed as “preventing, or at least minimising, hydrolytic, oxidative and enzymatic degradation caused by the harsh environment of the

human body, or at least to slow it down to a minimum that allows the interface to function over a long period of time before it eventually needs to be replaced”. The battery packs used to power these devices are another area under investigation. Efforts have been made to make these packs smaller overall and give them a less bulky appearance, with the aim of making them less intrusive for the patient. It is also important to limit the amount of power consumed by each implant, as this would reduce the amount of heat generated by the implant and thus minimise the risk of injury to the tissues located in the immediate vicinity of the implant.

{End of Chapter 19}

Chapter 20: Neuralink

Neuralink Corporation is a neurotechnology company specialising in the development of implantable brain-machine interfaces (BMIs). Elon Musk was one of the company's co-founders, and its headquarters are located in the Pioneer Building in San Francisco. These offices are shared with OpenAI.

Coordinates: 37.7623°N 122.4148°W

Since its foundation, the company has recruited a number of prominent neuroscientists from a wide range of institutions.

Elon Musk, Max Hodak, Ben Rapoport, Dongjin Seo, Paul Merolla, Philip Sabes, Tim Gardner, Tim Hanson and Vanessa Tolosa were the individuals who initiated the founding of Neuralink in 2016. Neuroscience, biology and robotics are just some of the fields represented within this group of specialists.

A story published in Fortune in January 2022 details complaints about the corporate culture at Neuralink from former employees who wish to remain anonymous. They described what they called a "culture of blame and fear"

, as well as one characterised by shifting goals. In a further alleged move to undermine management, Musk reportedly encouraged younger staff to “send problems and complaints directly to him”.

In 2018, Gizmodo published an article stating that Neuralink “remained very secretive about its work”, although public records showed that the company had attempted to open an animal testing facility in San Francisco. The company subsequently began research at the University of California, Davis.

An automated procedure carried out by a surgical robot involves inserting probes into the brain. These probes are usually made of polyimide, a biocompatible material, and have a thin conductor made of gold or platinum. Each probe has a wired region containing electrodes capable of localising electrical signals in the brain, as well as a sensory region where the wire interacts with an electronic system that enables the amplification and detection of the brain signal. The wired region of each probe is referred to as the detection region. Each probe has either 48 or 96 wires, and each of these wires has

32 independent electrodes, resulting in a system that can have up to 3,072 electrodes per array.

According to Neuralink, they have built a robot capable of rapidly inserting a large number of flexible probes into the brain. This could potentially circumvent the problems of tissue damage and lifespan associated with larger and stiffer probes.

A 1,536-channel recording system was made possible by Neuralink's development of an Application-Specific Integrated Circuit (ASIC). This system consists of 256 amplifiers that can be individually programmed (referred to as 'analogue pixels'), analogue-to-digital converters (referred to as 'ADCs') contained within the chip, and a peripheral circuit controller for serialising the received digitised information.

Neuralink subjects its products to rigorous testing by surgically implanting them into the living brains of animals such as pigs, monkeys and other animals.

Several experts in the field of neurology have shared their thoughts on Elon Musk and the other members of

Neuralink’s plan to develop a brain-computer interface.

{End of Chapter 20}

Chapter 21: Neural Dust

It is a type of brain-computer interface known as ‘neural dust’. Neural dust consists of nanometre-sized devices that act as nerve sensors whilst being powered wirelessly. The sensors can be used to examine, monitor or manipulate nerves and muscles, as well as to remotely monitor brain activity. In clinical settings, a medical treatment may involve the implantation of thousands of neural dust devices into the brains of human patients. The term derives from the phrase ‘smart dust’, which describes not only the concept but also the sensors used as neural dust.

The concept of neural dust was first presented in a paper published in 2011 by the Berkeley Wireless Research Centre at the University of California, Berkeley. In the paper, the authors described both the difficulties and the outstanding advantages of developing a wireless brain-computer interface (BCI) that could remain in place over an extended period.

Although brain-computer interfaces (BCIs) are one application for neural dust, neuroprosthetics (also known as neural prosthetics) may potentially find a use for it in the future. Although the terms are sometimes used interchangeably, the main difference between them is that brain-computer interfaces (BCIs) typically link a person's neural activity directly to a computer, whilst neuroprosthetics typically link activity in the central nervous system to a device designed to replace the function of a missing or impaired body part.

The sensor nodes are the main components of the neural dust system (neural dust), which are designed to be on the scale of 10–100 μm^3, with a subcranial interrogation device that would be positioned beneath the dura mater and serve as both a power source and a communication link to the neural dust.

Each of the neural dust particle devices contains a pair of recording electrodes, a custom-designed transistor and a piezoelectric sensor.

It is possible that the piezoelectric crystal detects brain activity from the extracellular space and converts it into an electrical signal.

Although there are a variety of BCIs, neural dust is in a category of its own due to its unique dimensions, wireless capability, and the use of ultrasonic technologies.

Whilst many such devices utilise electromagnetic waves (e.g. radio frequencies) to connect to wireless neural sensors, others use infrared wavelengths instead; this additional energy would be released into the environment as heat, which would result in damage to the surrounding tissue.

The use of ultrasound also makes it possible to increase the number of sensor nodes, enabling sizes of less than 100 μm. This opens up many avenues for research and development in the field of implantable electronics.

It would be difficult and practically impossible to develop a functioning transmitter within the sensor itself, as the neural dust particles are incredibly small. We therefore utilise backscatter communication, which is derived from RFID (Radio

Frequency Identification). When placed in close proximity to a radio-frequency (RF) interrogator – a device that transmits RF energy – passive RFID tags, which require no batteries, can both absorb and reflect the RF energy transmitted by the interrogator. When reflecting the RF energy back to the interrogator, they are able to modulate the frequency, enabling them to encode information as a by-product of this process. This strategy is used by Neural Dust and involves the subdural communicator transmitting an ultrasonic pulse, which is then reflected by the Neural Dust sensors. The neural signal is detected by the piezoelectric crystal from its position in the extracellular space. The ultrasonic energy reflected back to the interrogator is manipulated in such a way as to communicate the recorded activity.

Cochlear implants, which can help restore hearing, are an example of the type of neural prosthesis available. In combination with motor prostheses, the use of neural dust could enable far more nuanced control of movement.

Although therapeutic applications of techniques involving the electrical stimulation of nerves and brain tissue have been in use for some time, the small size and wireless nature of neural dust is enabling the development of these techniques in their clinical applications. Importantly, the risk of infection and scarring is considerable with conventional neurostimulation techniques, as well as with some types of nerve stimulation such as spinal cord stimulation. Both types of nerve stimulation use implanted electrodes that remain attached to cables. Whilst these risks are not an issue when using neural dust, the challenge of supplying the sensor node with a sufficient amount of electrical current remains a matter that needs to be addressed.

Electrostimulation devices have so far shown some success in the treatment of obstructive sleep apnoea (OSA). Researchers who treated patients with severe obstructive sleep apnoea using a surgically implanted electrostimulation device observed a significant improvement in their patients after 12 months of therapy with the device.

Through the use of radio-frequency-guided implants to stimulate the anterior sacral root region of the spine, electrical stimulation devices have proved beneficial in helping people with spinal cord injuries to regain their ability to urinate and defecate.

The use of electrical stimulation therapy in the treatment of epilepsy patients is a well-established method that has been in use for some time. Its origins can be traced back to the 1950s.

{End of Chapter 21}

Epilogue

A Billion Enlightened People

We live in a society dominated by change. Technological, economic and social developments have shaped the way people live and think. Globalised markets and technological revolutions are transforming the modern economy into a ‘knowledge-based society’, in which new ways of organising work govern the world and require the constant development of skills, the rapid dissemination of high-performance technologies, sound knowledge and increasing responsibility.

In the society of the future, knowledge will play a key role in the way of life that is specific to this knowledge-based society. Access to knowledge is a prerequisite for national cultural success, just as it is a prerequisite for economic competitiveness. The true knowledge-based society, as an expression of the globalised society, seeks to combine the needs of human nature – which is constantly growing and becoming ever more diverse – with its own regeneration, and to find ways of developing its inexhaustible resources: human intelligence, the spirit of innovation, associative creativity, and so on.

THE PROBLEM: Ignorance is the root of all evil

The problem I am trying to solve is ignorance, which involves a lack of necessary knowledge or understanding of what is happening around us.

Ignorance + poverty = crime Ignorance +

wealth = corruption Ignorance + freedom

= chaos Ignorance + authority = tyranny

Ignorance + religion = terrorism

But if you replace ‘ignorance’ with ‘knowledge’:

Knowledge + poverty = contentment

Knowledge + wealth = creativity

Knowledge + freedom =

happiness

Knowledge + authority = justice

Knowledge + religion = integrity

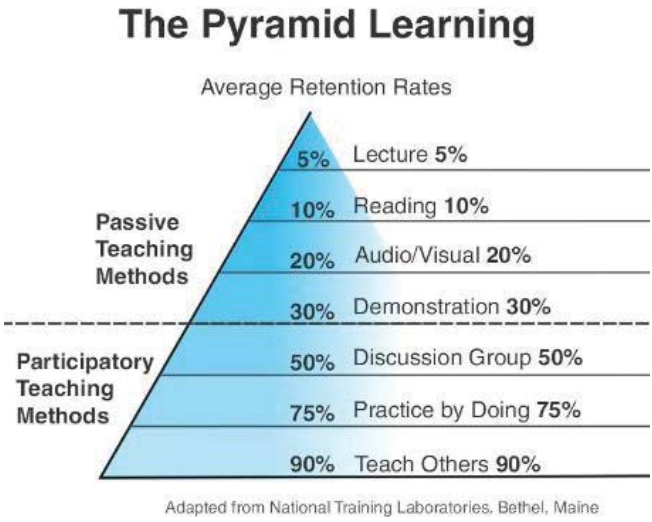
So I asked myself a question: if I could change just ONE aspect of the world to make it a better place, what would it be? I came to the conclusion that it would be to make people more knowledgeable. I felt that this aspect might have the power to bring about social change for a better world.

Ignorance may not be the root of all evil. Evil can be perpetrated through many different kinds of agendas. BUT ignorance is definitely a good explanation for why evil persists, and sometimes ignorance is the direct root cause.

Most people believe that knowledge is power and that success depends on how much a person knows. Knowledge is power, but knowledge without action can be useless; we gain knowledge through action; without action, knowledge is useless; and knowledge is not necessarily understanding.

Imagine you have a bucket. If, every time you tried to fill this bucket, 90 per cent of the water leaked out, you would probably not fill it until the leak had been fixed. Everything you read is like filling a bucket from which 90 per cent of the water leaks out. You retain only 10 per cent of what you read after 24 hours. Knowledge is power, but you're wasting time acquiring it if you retain very little of it. This is the key finding behind the study that gave rise to the learning pyramid.

Figure 6: The Learning Pyramid



THE SOLUTION: 1BK Community

So, if people are knowledgeable and can retain their knowledge by reading, listening and watching, and ultimately teach others to gain more knowledge, we will eradicate most of the roots of evil in this world.

This mission is perhaps the most important of our time. Together, we can achieve this. This mission is my attempt to fulfil the task of changing just ONE aspect of the world in an effort to make it a better place.

Sharing knowledge has a huge positive impact, so I have taken on an ambitious mission: to help one billion people gain more knowledge. As #1BK is a community, I ask you to join us so that, together, we can create a vast global community to make the world a better place, to combat ignorance by making you more knowledgeable, deeply aware, well-informed, broadly educated and wonderfully cultured, so that people are drawn to you for their own enlightenment.

The spirit of the One Billion Knowledgeable Movement is to give ideas a practical and useful form in the lives of the nations and peoples of the world. So I have taken on an ambitious mission to help one billion people become more knowledgeable – a One Billion Knowledgeable Movement – which I ask you to join so that, together, we can create a global community of knowledgeable individuals.

THE APPROACH: 1BK Factory

Recruiting ‘knowledge producers’ for general and specialised topics and supporting the production of knowledge in every possible format; in every possible language, with translation into over 100 languages; and through every possible channel; including marketplaces for e-books and audiobooks. This saves them time and effort, allowing them to focus on acquiring more knowledge.

Recruiting ‘knowledge contributors’ who contribute to a wide range of tasks, including translations, narration and illustrations.

The platform is essential for managing the process between producers, contributors and ‘knowledge consumers’; and offers incentives to produce more rather than simply consume knowledge.

The cycle will continue, and anyone can be a producer, contributor or consumer.

If every member can persuade 10 people to join, the community will certainly reach 1 billion in 10 years.

Building the ‘Knowledge Factory’ through software, automation and systems to produce knowledge content in any language and format, distribute it across multiple channels and maintain an online presence – website, social media, etc. – in every language, with a local community in every city.

THE ACTION: 1BK Moonshot

When humans launched a spacecraft into space to take a person to the Moon, they didn't know they would succeed, but they certainly had enough passion for it. A moonshot is a commitment to solving a problem before you know you can do it. #1BK is a moonshot, and together we can make it happen.

Encouraging knowledge consumers to become knowledge producers and contributors, and to earn more money in their e-wallet.

Join the movement at www.1BKOfficial.org by following three simple steps:

Step 1: Make knowledge your priority and recognise that knowledge is **your** birthright; invest in your knowledge by exploring the One Billion Knowledgeable resources to nurture your passion for knowledge.

Step 2: Get involved by promoting and enhancing **the knowledge** of the One Billion Knowledgeable initiative, and **by** creating new knowledge across all fields, in all formats and in all languages – simple enough for ordinary people to grasp, and detailed enough to make experienced professionals more informed.

Step 3: Spread the **word, pass it on** – tell ten people about the message you've learnt at www.1BKOfficial.org; those ten people will tell ten others, who will tell ten more, and in less than ten years the community will have a billion pieces of knowledge.

This mission is perhaps the most important of our time, and it's not a crazy idea – together, we can achieve this. I will tell the world that my priority is to be knowledgeable, and I will have the compassion within me to make others more knowledgeable, as this 'One Billion Knowledgeable' mission is taking place at a crucial time for humanity – because we need knowledgeable people to see things differently, to change things for the better. It drives humanity forward and leads the world towards enlightenment.

About the author

Fouad Sabry is the former Regional Head of Business Development for Applications at HP in Southern Europe, the Middle East and Africa (SEMEA). Fouad obtained his BSc in Computer Systems and Automatic Control in 1996, his Master's degree from the University of Melbourne (UoM) in Australia in 2008, his Master of Business Administration (MBA) in 2008, and his Master of Management in Information Technology (MMIT) in 2010.

Fouad has over 20 years' experience in the fields of information technology and telecommunications and has worked for local, regional and international companies such as Vodafone and IBM in the Middle East and Africa (MEA) region. Fouad joined HP Middle East (ME), based in Dubai, United Arab Emirates (UAE), in 2013 and helped develop the software business across dozens of markets in Southern Europe, the Middle East and Africa (SEMEA). Fouad is currently an entrepreneur, author and futurist, focusing on emerging technologies and industry solutions, and is the founder of the One Billion Knowledgeable (1BK) initiative.

Where can I find the author online?

Website: www.1bkofficial.org

Twitter: @fouadsabry

Facebook: www.facebook.com/OfficialFouadSabry

LinkedIn: www.linkedin.com/in/fouadsabry/

Blog: https://medium.com/@fouadsabry

Coming soon

New technologies are those technical innovations that represent advanced developments in a particular field, offering competitive advantages.

New technologies generally go through the following sequential phases:

1 - Hypothetical

2 - Research and development / experimental / pilot projects

3 - Working demonstrators

4 - Commercialisation / dissemination

The appendices on new technologies for each sector provide an insight into the forthcoming books.

Appendices: New technologies in each sector

Appendix 1: New technologies in agriculture

Agricultural robotics

Status:

Research,

development and pilot

projects

Possible applications:

Not applicable **Related**

technologies:

Agricultural drones Closed

ecological systems **Status**:

Research,

development

Functioning demonstrators (e.g. Biosphere 2)

Potential applications:

Agriculture, scientific

research, space colonisation

Related technologies:

Greenhouse,

Biosphere 2,

Eden Project,

Bio-Shelter

Seawater greenhouse

Perpetual harvest greenhouse system

Cultured meat

Status:

Research and

development

Potential applications: Human

Resource-efficient

Healthier and cheaper meat

Related technologies:

New Harvest

Vertical farming

Status:

Research

Developmen

t,

experiments

,

disseminatio

n

Possible applications:

Plant and meat production

Related technologies: Not

applicable

Appendix 2: New technologies in aviation

Headset with neural recognition

Status:

Research and development

Potential applications: Pilot assistance

Related technologies:

Transcranial neural sensing and characterisation Brain-computer interface Neuroprostheti

cs, ion propulsion

Status:

In common use

Possible applications:

Propulsion of spacecraft

Related technologies: Not applicable

Plasma propulsion

Status:

Research and

development

Possible applications:

Spacecraft propulsion

Related technologies: Not

applicable

Automatic visual inspection of aircraft

Status:

Research,

development,

prototypes

Potential applications:

Aircraft maintenance, repair and operation

Related technologies:

Airbus

Donecle

Hal

A*STERN

Appendix 3: New Technologies in Construction

Claytronics

Status:

Hypothetical

Experiment

Possible applications: Not applicable **Related technologies:** Not applicable Four-dimensional printing

Status:

Research and Development

Possible applications:

Not applicable **Related technologies**: Not applicable Molecular assembler

Status:

Hypothetical

Experimental

Possible applications:

Not applicable **Related**

technologies:

Replicator (Star Trek)

Von Neumann Universal Constructor

Utility Nebula

Status:

Hypothetical

experiment

Possible applications:

Not applicable **Related**

technologies: Not

applicable

Appendix 4: New Technologies in Architecture

Arcology

Status:

Research,

Development,

Commercialisation

Possible applications: Not

applicable

Related technologies:

Not applicable

Dome city

Status:

In progress

Potential applications:

Weather-controlled city

Colonisation of other celestial

bodies Dubai Mall of the World

project

Related technologies:

Not applicable

Appendix 5: Emerging technologies in materials

Aerogel

Status:

Hypothetical

Experiments

Adoption

Early uses

Possible applications:

Improved insulation;

insulating glass (when

transparent); casings

for oil pipelines;

aerospace

High-temperature applications;

extreme-cold applications

Related technologies:

Not applicable

Amorphous metal

Status:

Experiments

Possible applications:

Armour

Related technologies:

Not applicable

Bioplastic **Status:**

Commercialisation and

adoption

Potential applications:

Recyclable packaging,

single-use items

Related technologies:

Not applicable

Conductive polymers

Status:

Research,

experiments,

prototypes

Potential applications:

Lighter and cheaper wires

Antistatic materials Organic

solar cells

Related technologies:

Jacquard weaving

Cryogenic treatment

Status:

Research, experiments,

prototypes

Possible applications:

Oil and gas blowout preventers (BOPs), jet

engines

Power turbines,

locomotives, electric

vehicles, gearboxes

Bearings

Related technologies:

Not applicable Dynamic

armour

Status:

Prototypes

Potential applications:

Improved protection for ships against shaped-charge weapons

Related technologies:

Not applicable

Fullerene

Status:

Experiments and

dissemination

Potential applications:

Programmable matter

Related technologies:

Not applicable

Graphene

Status:

Hypothetical

Experiments

and

applications

Early uses

Potential applications:

Components with a higher strength-to-weight ratio

Transistors operating at higher frequencies Lower costs

for screens in mobile devices Hydrogen storage for fuel

cell cars Sensors for diagnosing diseases

More efficient batteries

Related technologies:

Not applicable

Lab-on-a-chip

status:

Some commercialisation

Possible applications:

Not applicable **Related**

technologies: Not

applicable

High-temperature
superconductivity

Status:

Hypothetical,

prototype,

experimental

Possible applications:

Loose conductors,

frictionless bearings,

magnetic levitation

trains

Lossless high-performance batteries, electric cars

Heat-free integrated circuits,

processors

Related technologies:

Cryogenic receiver front-end (CRFE) RF microwave filter

systems for mobile phone base stations Prototypes in dry ice

Hypothetical and experimental studies for higher temperatures

Magnetic nanoparticles

Status:

Under development

Possible applications:

Not applicable **Related technologies:** Not applicable

Magnetorheological fluid

Status:

Research and development

Potential applications:

Magnetorheological dampers, heavy-duty engine damping, driver's seat/cab damping in construction vehicles

Seismic dampers in buildings absorb harmful shock waves and vibrations within the structure, making them earthquake-resistant

Improve the bullet-resistance of body armour fluid

Humvees

Various other off-road vehicles use dynamic MR shock absorbers / dampers.

Magnetorheological equipment was used in the construction of the Hubble Space Telescope's corrector lens

A vehicle's suspension shock absorbers are filled with magnetorheological fluid.

Related technologies:

Electrorheological fluid

Microfluidics

Status:

Not applicable

Possible applications:

Not applicable **Related technologies:** Not applicable

High-temperature superfluidity

Status:

Commercialisation

Potential applications:

Superfluid gyroscopes operate at extremely low temperatures

High-precision measurement of

gravity; navigation and manoeuvring

devices,

Potential devices for emitting gravitomagnetic fields

Frictionless mechanical devices

Related technologies:

Not applicable

Metamaterials

Status:

Hypothetical

Experiments

Prevalence

Possible applications:

Microscopes,

cameras

Metamaterial casing Covers

Related technologies:

Not applicable

Metal foam **Status:**

Research

Commercialisation

Potential applications:

Space colonies,

floating cities

Related technologies:

Not applicable

Multifunctional

structures

Status:

Hypothetical,

experiments,

prototypes

Few commercial

Possible applications: Self-monitoring

Self-healing material

Morphing

Related technologies:

Not applicable

Nanomaterials: carbon nanotubes

Status:

Hypothetical

Experiments

Applications

Early uses

Possible applications:

Stronger and lighter materials

Space lift

Related technologies: Carbon

nanotubes, carbon fibre

Programmable matter

Status:

Hypothetical

experiments

Possible applications:

Claytronics Synthetic

biology

Related technologies:

Not applicable

Quantum dots

Status:

Research,

experiments,

prototypes,

commercialised

Possible applications:

Quantum dot lasers,

quantum dot displays

Future use as programmable matter in display

technologies (TV, projection)

Optical data communication (high-speed data

transmission)

Medicine (laser scalpel)

Related technologies:

Not applicable

Silicen

Status:

Hypothetical research

Possible applications:

Not applicable **Related technologies:** Not applicable

Superalloy

Status:

Research and adoption

Possible applications:

Aircraft engines

Related technologies:

Not applicable

Synthetic diamond

Status:

Research and commercialisation

Potential applications:

Electronics

Related technologies:

Not applicable

Time crystals

Status:

Research and experiments

Potential applications:

Quantum computers with stable qubits

Related technologies:

Not applicable

Translucent concrete

Status:

Commercialisation

Potential applications:

Construction of

skyscrapers and towers

Sculptures such as Europe Gate

Related technologies:

Not applicable

Hypereutectic alloy **Status:**

Research,

commercialisation

Possible applications:

Metals

Related technologies:

Hypereutectic piston

Super-plastic alloy **Status:**

Research and

commercialisation

Potential applications:

Metals

Related technologies:

Superplasticity

Appendix 6: New Technologies in Optoelectronics

Drone display

Status:

Commercialisation and adoption

Possible applications: Artistic uses, advertising

Related technologies: Swarm robotics

Flexible display

Status:

Research, commercialisation, adoption

Possible applications:

Displays on curved surfaces

Electronic scrolls Wearable technology

Related technologies:

Electronic paper

3D displays and volumetric displays

Status:

Research,

prototypes,

commercialisation

Potential applications:

Television, computer

interfaces, cinemas

3-dimensional images

Related technologies:

autostereoscopic display,

stereoscopic display, volumetric

display, holographic display, light

field display

Nintendo 3DS

Swept-volume display

Laser video displays

Status:

Commercialisation

Adoption

Possible applications:

First commercial laser television in 2008:

Mitsubishi LaserVue television

Displays with a very wide colour gamut

Related technologies:

Laser TV

Holography

Status:

Adoption

Possible applications:

Not applicable **Related**

technologies:

Holographic display Computer-

generated holography

Optical transistor

Status:

Prototypes

Possible applications:

Not applicable **Related**

technologies: Not

applicable Screenless

display

Status:

Hypothetical

experiments

Possible applications: Virtual

retinal display, bionic

contact lens, augmented

reality, virtual reality

Augmented reality could enable the user to view blueprints in 3D, as in a building yard

Provides the user with constantly updated information on the stock market, the user's company and meeting status

Visual impairments

Related technologies:

Head-mounted display,

head-up display,

adaptive optics

EyeTap,

Google Glass

Microsoft HoloLens

AR Cloud

Appendix 7: New technologies in electronics

Biometrics

Status:

Adoption

Possible applications:

Not applicable **Related technologies:** Not applicable

Digital scent technology

Status:

Adoption

Possible applications:

Not applicable **Related technologies:**

Smell-O-Vision iSmell

Electronic nose

Status:

Research

Commercialisation

Potential applications:

Detecting spoiled food Chemical weapons

Cancer

Related technologies:

Not applicable

E-textiles

Status:

Research and disseminati on

Possible applications:

Not applicable **Related technologies:** Not applicable

Flexible electronics

Status:

Commercialisation, Research, Development

Prototypes

Potential applications:

Flexible and foldable electronic devices (e.g. smartphones)

Flexible solar cells that are lightweight, can be rolled up for transport and are easy to use

Related technologies:

Nokia Morph

Flexible organic light-emitting diode

Memristor

Status:

Prototype

Potential applications:

Smaller, faster memory with lower power consumption

Analogue electronics

Programmable signal

processing Neural networks

Control systems

Reconfigurable computing

Brain-computer interfaces (BCI)

RFID (RFID)

Pattern recognition

Related technologies:

Not applicable

Molecular electronics

Status:

Research and development

Potential applications:

Not applicable **Related technologies:** Not applicable

Nanoelectromechanical systems

Status:

Research and development

Potential applications:

Not applicable

Related technologies:

Not applicable Solid-

state transformer **Status:**

Development,

prototypes

Possible applications:

Not applicable **Related**

technologies: Not

applicable

Spintronics

Status:

Prototypes

Potential applications:

Data storage,

computer equipment

Related technologies:

MRAM

Thermal copper pillar junction

Status:

Prototypes

Possible applications: Cooling

of the circuit; microfluidic

actuators

Thermoelectric power generation using small devices

Related technologies:

Holographic ultra-high-definition disc Metal-

insulator transition

Three-dimensional integrated circuit

Status:

Development,

commercialisation

Potential applications:

Storage processing,

data processing

Related technologies:

Not applicable

Twistronik

Status:

Under development

Possible applications:

Not applicable **Related technologies:** Not applicable

Appendix 8: New technologies in the energy sector

Wind turbine in the air

Status:

Research

Potential applications:

Electricity generation

Related technologies:

KiteGen

Americium battery

Status:

Research

Potential applications:

Estimated operational battery in 5–10 years from 2019.

Related technologies:

Not applicable

Artificial photosynthesis

Status:

Research and

experiments

Potential applications:

Growing interest in a global macro-science project

Enhancing natural photosynthesis so that road infrastructure and vehicles can convert sunlight and water into hydrogen, and carbon dioxide into carbohydrates

Related technologies:

Sustainocene,

renewable energy,

nanotechnology

Concentrated solar energy

Status:

Commercialisation

Potential applications:

Growing markets in California, Spain and North Africa;

electricity generation

Related technologies:

DESERTEC

BrightSource Energy

Solar Millennium

Cryogenic treatment

Status:

Prototype

Potential applications:

Underwater and deep-sea oil and gas exploration Power generation from wind power and fossil fuels Nuclear power

Oil and gas blowout preventers (BOPs) Jet engines

Power turbines, locomotives, electric vehicles, gears and bearings

Related technologies:

Not applicable

Electrical double-layer capacitor

Status:

Diffusion, further development

Potential applications:

Regenerative braking

Energy storage: generally faster charging, longer-lasting, more flexible, greener

Related technologies:

Not applicable

Energy harvesting

Status:

Experiments

Potential applications:

Constant energy source for mobile devices

Portable and ubiquitous devices

Related technologies:

Humavox

Flywheel energy storage

Status:

Commercialisation

Potential applications:

Not applicable

Related technologies:

Not applicable

Fusion power

Status:

Research and

experiments

Potential applications:

Generation of electricity and heat; molten salt reactor

recycling using waste heat

Related technologies:

ITER

, NIF

Wendelstein 7-X

Magnetic confinement fusion

Focus on dense plasma

Muon-catalysed fusion

Generation IV nuclear reactor

Status:

Research

Experiments

Potential applications:

Electricity generation,

heat

Transmutation of nuclear waste from conventional reactors

Related technologies:

Not applicable

Gravity battery

Status:

Prototype

Possible applications:

Not applicable **Related technologies:** Not applicable

Grid energy storage

Status:

Commercialisation

Potential applications:

Not applicable

Related technologies:

Not applicable

Home Fuel Cell

Status:

Research

Commercialisation

Potential applications:

Off-grid

Power generation using an environmentally friendly fuel as a backup during prolonged power cuts.

Related technologies:

Autonomous

construction, Bloom

Energy Server

Hypercapacitor

Status:

Research

Possible applications:

Not applicable

Related technologies:

Not applicable

Lithium-air battery

Status:

Research, experiments

Potential applications:

Laptops, mobile phones, long-range electric cars; energy storage for the electricity grid

Related technologies:

Not applicable

Lithium iron phosphate battery

Status:

Commercialisation

Potential applications:

Not applicable **Related technologies:** Not applicable

Lithium-sulphur battery

Status:

Research and development

Potential applications:

Not applicable **Related**

technologies: Not

applicable

Magnesium battery

Status:

Early commercialisation

Potential applications:

Not applicable **Related**

technologies: Not

applicable

Magnonics

Status:

Research

Potential applications:

Data storage

Related technologies:

Not applicable

Liquid salt reactor

Status:

Research, experiments

Potential applications:

Generation of electricity and heat

Related technologies:

Not applicable

Nanowire battery

Status:

Experiments, prototypes

Potential applications:

Laptops, mobile phones, long-range electric cars; energy storage for the electricity grid

Related technologies:

Not applicable

Nantenna

Status:

Research

Potential applications:

Power generation **Related**

technologies: Not

applicable

Ocean thermal energy conversion

Status:

Prototype

Potential applications:

Not applicable **Related**

technologies: Not

applicable

Solid-state battery

Status:

Niche applications

Potential applications:

Hybrid cars

Related technologies:

Not applicable

Smart grid

Status:

Research, deployment

Possible applications:

Not applicable **Related**

technologies:

Smart meter, SuperSmart Grid

Space-based solar energy

Status:

Hypothetical

Possible applications:

Not applicable **Related**

technologies: Not

applicable

Thorium nuclear fuel cycle

Status:

Research began in the 1960s and is not yet complete

Potential applications:

Generation of electricity and heat

Related technologies:

Not applicable

Vortex engine

Status:

Not applicable

Possible applications:

Power generation.

Related technologies:

Not applicable

Wireless power transmission

Status:

Prototypes, widespread adoption, short-range consumer products

Potential applications:

Wirelessly powered devices: laptops, mobile phones,

electric cars, etc.

Related technologies:

WiTricity, resonant inductive coupling

Zero-energy buildings

Status:

Expansion

Potential applications:

All houses

Related technologies:

Passive House

Appendix 9: New technologies in the entertainment industry

Computer-generated images

Status:

Under development

Possible applications:

Films, photographs

Related technologies:

Deepfake, StyleGAN, DeepDream

Immersive virtual reality

Status:

Hypothetical, limited commercialisation

Possible applications:

An artificial environment in which the user feels just as immersed as they normally do in conscious reality.

Related technologies:

Virtusphere, 3. Space Vest, haptic suit, immersive technology, simulated reality, holodeck (fictional)

Ultra-high-definition television

Status:

Commercialised **Possible applications:** Not applicable **Related technologies:** Not applicable

Appendix 10: Emerging technologies in telecommunications

5G mobile communications

Status:

Adoption

Potential applications:

Mobile phones, tablets

Related technologies:

Not applicable

6G mobile

communications

Status:

Conceptual

Potential applications:

Mobile phones

Related technologies:

Not applicable

Li-Fi

Status:

Demos, requires standardisation

Potential applications:

Not applicable

Related technologies:

Not applicable

Nanoradio

Status:

Research & Development, Diffusion

Possible applications:

Not applicable **Related technologies:** Not applicable

Navigation Doppler Lidar

Status:

Under development

Potential applications:

Not applicable **Related technologies:** Not applicable

Quantum radar

Status:

Prototypes

Potential applications:

Not applicable **Related**

technologies: Not

applicable

Radio Frequency Identification

Status:

Widespread use, high costs

Possible applications:

Smartstores – RFID-based self-checkout (tracking of all incoming and outgoing products), food packaging, smart shelves, smart shopping trolleys. See: Possible applications

Related technologies:

Not applicable

Software-Defined

Radio **Status:**

Development, commercialisation

Possible applications:

Cognitive radio, mesh networks, software-defined antenna

Related technologies:

GNU Radio, list of software-defined radios, Universal Software Radio Peripheral

X-ray communication

Status:

Demonstrations

Possible applications:

Not applicable **Related technologies:** Not applicable

Appendix 11: Emerging technologies in information technology

Ambient intelligence

Status:

Hypothetical

Possible applications:

Not applicable **Related technologies:** Not applicable

Artificial Brain

Status:

Research

Potential applications:

Treatment of neurological disorders, artificial intelligence

Related technologies:

Blue Brain Project, Human Brain Project

Artificial General Intelligence

Status:

Hypothetical, experimental

Possible applications:

Creation of intelligent devices and robots; AI can advise (or even take charge of) scientific projects, government, the military, corporate governance, film and book production, inventions, etc.

Related technologies:

Advances in artificial intelligence, technological singularity, applications of artificial intelligence,

Atomtronics

Status:

Hypothetical

Possible applications:

Not applicable **Related technologies:** Not applicable

Augmented reality

Status:

Adoption

Possible applications:

Not applicable

Related technologies:

Google Glass, Windows Mixed Reality, Microsoft HoloLens, mixed reality, smart glasses, Pokémon Go

Blockchain or distributed ledger technology

Status:

Adoption

Potential applications:

Elimination or reduction of transaction costs; distributed, open and transparent records; non-hierarchical networked systems; cryptography

Related technologies:

Bitcoin, digital currency, cryptocurrency, e-democracy

Carbon nanotube field-effect transistor

Status:

Research and development

Potential applications:

Extension of Moore’s Law

Related technologies:

Not applicable

Civilian technology

Status:

Research and development, projects

Potential applications:

Smart Cities, more responsive government

Related technologies:

Citizen technology, smart city, e-democracy, open data, smart environment

Cryptocurrency

Status:

Adoption

Potential applications:

Money supply, global reserve currency

Related technologies:

Bitcoin, digital currency,

digital DNA data storage **Status:**

Experiments

Potential applications:

Mass data storage

Related technologies:

Not applicable

Exascale computing

Status:

Projects

Potential applications:

Not applicable **Related**

technologies: Not

applicable

Gesture recognition

Status:

Adoption

Possible applications:

Not applicable **Related**

technologies: Not

applicable

Internet of Things

Status:

Adoption

Potential applications:

Not applicable **Related**

technologies: Not

applicable

New storage technologies

Status:

Under development

Potential applications:

Not applicable **Related**

technologies:

T-RAM, memristor, Z-RAM, TTRAM, CBRAM, SONOS, RRAM, Track-based memory, NRAM, phase-change memory, FJG RAM, centipede memory, skyrmion, programmable metallisation cell, 3D XPoint, ferroelectric RAM, magnetoresistive random-access memory, nvSRAM

New magnetic data storage technologies

Status:

Under development (HAMR, BPM); in decline (SMR)

Potential applications:

Significantly improved storage density compared to current HDDs, can be combined

Related technologies:

SMR, HAMR, BPM, MAMR, TDMR, CPP/GMR, PMR, Hard disk drive

Fourth-generation optical discs (3D optical data storage, holographic data storage) **Status:**

Research, prototyping

Potential applications:

Storing and archiving data that was previously deleted for economic reasons

Related technologies:

Blu-ray Disc, optical storage

General-purpose computing on graphics processing units

Status:

Widespread use of non-standardised methods

Possible applications:

Orders of magnitude faster processing of parallelisable algorithms

Related technologies:

Not applicable

Exocortex

Status:

Diffusion of primitive reinforcements; working prototypes of more; hypothetical experiments on stronger reinforcement

Possible applications:

Not applicable **Related technologies:** Not applicable

Machine translation

Status:

Widespread use

Potential applications:

Simpler and more cost-effective intercultural communication

Related technologies:

Not applicable Industrial

image processing **Status:**

Research, prototyping, commercialisation

Possible applications:

Biometrics, process control (e.g. in driverless cars, automated guided vehicles), event detection (e.g. in visual surveillance), interaction (e.g. in human-computer interaction), robot vision

Related technologies:

Computer vision, pattern recognition, digital image processing

Mobile collaboration and e-learning

Status:

Development, commercialisation

Potential applications:

Expands the capabilities of video conferencing for real-time use on mobile handheld devices via secure networks. For use in various sectors such as manufacturing, energy and healthcare. Teleworking

Related technologies:

Not applicable

Multimodal contactless biometric facial/iris systems

Status:

Deployed at various airports and federal security checkpoints

Possible applications:

Unimodal facial recognition scanners

Related technologies:

Not applicable

Neuromorphic engineering

Status:

Research & Development

Possible applications:

Not applicable **Related technologies:** Not applicable

Optical computing

Status:

Hypothetical, experimental; some integrated circuit components have been developed

Potential applications:

Smaller, faster and more energy-efficient data processing

Related technologies:

Not applicable

Quantum computing

Status:

Hypothetical, experiments, commercialisation

Potential applications:

Much faster computation for certain types of problems, chemical modelling, new materials with programmed properties, hypothetically high-temperature superconductivity and superfluidity

Related technologies:

Not applicable

Quantum cryptography

Status:

Commercialisation

Potential applications:

Secure communication

Related technologies:

Not applicable

Semantic Web or Answer Machine

Status:

Research, limited use

Possible applications:

Make the web machine-readable by annotating data on the web based on its meaning

Related technologies:

Corporate Semantic Web, Semantic Web Services, Semantic Web Stack, Web 3.0

Smart speaker

Status:

Commercialisation

Possible applications:

Home automation, communication with people and machines

Related technologies:

Amazon Echo, Google Home, HomePod

Speech recognition

Status:

Research, development, commercialisation

Possible applications:

Not applicable **Related technologies:** Not applicable

Subvocal recognition

Status:

Research, development, commercialisation

Potential applications:

Not applicable **Related technologies:** Not applicable

Virtual reality

Status:

Adoption

Potential applications:

Entertainment, education

Related technologies:

Oculus Rift, HTC Vive, PlayStation VR

Hybrid forensics

Status:

Research, commercialisation

Potential applications:

digital forensics, electronic detection, malware detection, IT compliance

Related technologies:

Not applicable

Appendix 12: Emerging technologies in the medical sector

Artificial womb

Status:

Hypothetical, research

Possible applications:

Space travel, extracorporeal pregnancy, reproductive genetics, same-sex reproduction

Related technologies:

Not applicable Body

implants, prostheses **Status:**

Studies, ranging from animal studies (e.g. brain implants) through clinical trials in humans (e.g. insulin pump implants) to commercial production (e.g. pacemakers, joint replacements, cochlear implants)

Possible applications:

Brain implant, retinal implant

Related technologies:

Prosthetics, prosthetics in fiction, cyborg

Cryonics

Status:

Hypothetical, research, commercialisation (e.g. Alcor, Cryonics Institute)

Possible applications:

Life extension **Related technologies:**

Not applicable

Extinction **Status:**

Research, development, trials

Possible applications:

Livestock farming, pets, zoos

Related technologies:

Recreation of woolly mammoth species Injection of human DNA **Status:**

Clinical trials

Potential applications:

Not applicable

Related technologies:

Not applicable

Enzybiotics **Status:**

Successful initial trials

Possible applications:

Not applicable **Related**

technologies: Not

applicable

Genetic engineering of organisms and viruses

Status:

Research, development, commercialisation

Possible applications:

Creation and modification of species (primarily to enhance their physical and mental abilities), biomachines, elimination of genetic disorders (gene therapy), production of new materials, healthier and cheaper food, manufacture of medicines and vaccines, research in the natural sciences, bioremediation, detection of arsenic, CO_2-reducing superplants

Related technologies:

Biopunk, genetically modified food, superhuman, human enhancement, transhumanism, gene doping, designer baby, genetic pollution

Idle state or paused animation

Status:

Research, development, animal testing

Possible applications:

Organ transplantation, space travel, prolonged surgery, emergency care

Related technologies:

Not applicable

Life extension, strategies for negligible senescence

Status:

Research, experiments, animal trials

Potential applications:

Extended lifespan

Related technologies:

Immortality, biological immortality

Nanomedicine

Status:

Research, experiments, limited use

Possible applications:

Not applicable **Related technologies:** Not applicable

Nanosensors

Status:

Research and development

Potential applications:

Not applicable **Related technologies:** Not applicable

Omni-processor

Status:

Research and development; some prototypes

Potential applications:

Not applicable

Related technologies:

Not applicable

Oncolytic virus **Status:**

Human trials (Talimogene laherparepvec, Reolysin, JX-594), commercialisation (H101)

Potential applications:

Cancer therapy, imaging

Related technologies:

Oncolytic virus

Personalised medicine, whole-genome sequencing

Status:

Research, experiments

Potential applications:

Personalised medical procedures, genome sequencing during drug trials

Related technologies:

Personalised genomics

Phage therapy

Status:

Initial pilot applications

Potential applications:

Not applicable **Related**

technologies: Not

applicable

Plantibody

Status:

Clinical trials

Potential applications:

Not applicable **Related**

technologies: Not

applicable

Regenerative medicine

Status:

Some laboratory trials

Potential applications:

Life extension

Related technologies:

Not applicable

Robotic surgery

Status:

Research, dissemination

Potential applications:

Not applicable **Related technologies:** Not applicable

Senolytic

Status:

Under investigation

Potential applications:

Not applicable **Related technologies:** Not applicable

Stem cell therapies

Status:

Research, experiments, Phase I clinical trial for the treatment of spinal cord injuries in humans (GERON), cultured corneal transplants

Potential applications:

Treatment of a wide range of diseases and injuries

Related technologies:

Stem cells, stem cell therapies, skin cell gun,

synthetic biology, synthetic genomics

Status:

Research, development, first synthetic bacteria in May 2010

Potential applications:

Creation of infinitely scalable production processes based on programmable bacterial species and other life forms

Related technologies:

BioBrick, iGEM, synthetic genomics

Tissue engineering

Status:

Research, dissemination

Possible applications:

Organ printing, tooth regeneration

Related technologies:

Not applicable

Tricorder

Status:

Research and development

Possible applications:

Diagnosis of diseases

Related technologies:

Medical tricorder

Viral therapy

Status:

Research, human trials

Possible applications:

Gene therapy, cancer therapy

Related technologies:

Viral therapy, oncolytic virus

Vitrification or cryoprotectant

Status:

Hypothetically, some experiments

Possible applications:

Organ transplantation, cryonics

Related technologies:

Not applicable

Appendix 13: New technologies in the neurosciences

Brain-computer interface

Status:

Research and commercialisation

Potential applications:

Faster communication, faster learning and ‘more authentic’ interaction (generating emotions and information in the brain on demand). Controlling emotions in people with mental health conditions

Related technologies:

Experience machine, Neuralink, stent-electrode recording array

Mind-reading, neuroinformatics

Status:

Research

Possible applications:

Not applicable

Related technologies:

Not applicable

Electroencephalography

Status:

Research, Diffusion

Potential applications:

Control of electronic devices via brainwaves

Related technologies:

BrainGate brain-computer interface

Status:

Success in animal trials, including a two-subject trial; human surgery as early as 2019

Potential applications:

Treat debilitating diseases or severe disfigurements

Related technologies:

Brain transplantation, hand transplantation, organ transplantation

Neuroprosthetics

Status:

Not applicable

Possible applications:

Visual prosthesis, brain implant, exocortex, retinal implant, Neurograin

Related technologies:

Not applicable

Sonogenetics

Status:

Research; experimentation

Possible applications:

Not applicable **Related technologies:** Not applicable

Appendix 14: New Technologies in the Military

Caseless ammunition

Status:

Field trials and some niche markets

Potential applications:

Warfare

Related technologies:

Light small arms technologies

Camouflage device

Status:

Successful experiments in which small objects were cloaked under certain conditions

Possible applications:

Cloaking microscope tips at optical frequencies

Related technologies:

Metamaterial cladding,

directed-energy weapon **Status:**

Research, development, some prototypes

Possible applications:

Warfare

Related technologies:

Laser weapon system

Electrolaser

Status:

Research and development

Possible applications:

Not applicable **Related technologies:** Not applicable

Electromagnetic weapons

Status:

Research and development

Potential applications:

Warfare

Related technologies:

Coil gun, railgun

Electrothermal-chemical technology

Status:

Research and development

Potential applications:

Armoured, artillery and close-quarters combat weapon systems

Related technologies:

Not applicable

Force field

Status:

Hypothetical, experimental

Possible applications:

Military and law enforcement, space exploration

Related technologies:

Plasma

window, Green

sphere **Status:**

Under development

Potential applications:

Environmentally friendly ammunition

Related technologies:

Not applicable

Hypersonic cruise missile

Status:

Under development

Possible applications:

Glide vehicles and cruise missiles capable of reaching 5 times the speed of sound or more.

Related technologies:

Avangard, Kinzhal, Zircon, BrahMos-II, Prompt Global Strike, DARPA Falcon Project, DF-ZF, Boeing X-51 Waverider

Laser weapon

Status:

Research and development, trials

Possible applications:

Tracking and destruction of missiles, bombs, drones, etc.

Related technologies:

Advanced Tactical Laser, High-Energy Liquid Laser Area Defence System

MAHEM

Status:

Research, under development

Potential applications:

An alternately shaped penetrator that could replace self-forging explosives with molten metal to penetrate enemy armour.

Related technologies:

Explosion-pumped flux compression generator

Particle beam weapon

Status:

Hypothetical

Possible applications:

Not applicable **Related technologies:**

Strategic Defence Initiative

Plasma weapon

Status:

Hypothetical

Possible applications:

Not applicable

Related technologies:

Not applicable Precision-guided firearm **Status:**

Research and development

Potential applications:

Warfare

Related technologies:

EXACTO, Smart Bullet

Pure fusion weapon

Status:

Hypothetical

Possible applications:

Not applicable **Related technologies:** Not applicable

Acoustic Weapons

Status:

Research, development, commercialisation

Possible applications:

A weapon that can be used to either disorient, incapacitate or kill an opponent using sound, infrasound or ultrasound.

Related technologies:

Long-range acoustic device

Stealth technology

Status:

Research and development

Potential applications:

Electronic countermeasures

Related technologies:

Plasma stealth, stealth aircraft, radar-absorbing material

Telescopic ammunition

Status:

Research and development

Possible applications:

A type of ammunition that encases a bullet with a powder charge and encloses it within a cartridge.

Related technologies:

Not applicable

Lightweight Small Arms Technologies Programme

Status:

Research and development

Potential applications:

Warfare

Related technologies:

Lethal autonomous weapon

Appendix 15: Emerging technologies in space exploration

Artificial gravity

Status:

Research and development

Possible applications:

Space travel

Related technologies:

Spin-gravity

asteroid mining **Status:**

Hypothetically, NASA has announced plans to capture and redirect an asteroid.

Possible applications:

Trade, resource supply

Related technologies:

Not applicable

Hyper-telescope

Status:

Hypothetical

Possible applications:

Astronomy

Related technologies:

Not applicable

Starshot

Status:

Research

Potential applications:

Unmanned interstellar probes

Related technologies:

Not applicable

Stasis chamber

Status:

Experimental, research and development

Potential applications:

Interplanetary spaceflight, interstellar spaceflight, medicine

Related technologies:

Not applicable

Solar gravitational lens

Status:

Hypothetical

Possible applications:

Space observation

Related technologies:

FOKAL

Inflatable space habitat

Status:

Developed, prototypes built and tested

Potential applications:

Space habitats

Related technologies:

Bigelow Aerospace

Miniaturised satellite

Status:

Development, early commercialisation, diffusion

Potential applications:

Low-cost satellites, constellations for low-data-rate communications, use of formations to collect data from multiple points, inspection of larger satellites in orbit.

Related technologies:

Not applicable

Reusable rocket technology for orbital launch vehicles

Status:

Several companies, including Blue Origin and SpaceX, are developing these technologies.

Potential applications:

Disposable launch vehicles may become prohibitively expensive, with the exception of national government or military missions.

Related technologies:

New Glenn, SpaceX spacecraft

Appendix 16: New technologies in robotics

Android, Gynoid

Status:

Research, development, prototypes, diffusion, commercialisation

Possible applications:

Care for people with disabilities, childcare and care for the elderly, domestic work, sex worker, flight attendant, model, hostess, waiter, security guard

Related technologies:

Not applicable

Gastronomy robots

Status:

A few prototypes

Possible applications:

Not applicable **Related technologies:** Not applicable

Molecular nanotechnology, nanorobotics

Status:

Hypothetical, experimental

Possible applications:

Machines (desktop, industrial) capable of manufacturing anything given the materials (e.g. Rotimatic), low-cost planetary terraforming

Related technologies:

Not applicable Powered

exoskeleton **Status:**

Research, development, prototyping, dissemination, commercialisation

Possible applications:

Heavy lifting, paralysis, muscular disorders, warfare, construction, firefighting, care for the elderly and disabled.

Related technologies:

LOPES (exoskeleton), ReWalk, Human Universal Load Carrier, fictional armour (Iron Man's armour), Future Force Warrior

Self-configuring modular robot

Status:

Hypothetical, experiments, early prototypes

Potential applications:

As a universal physical machine, SRCMR has the potential to transform the way we manufacture many physical structures and machines

Related technologies:

Robots, swarm robotics, autonomous research robots

Swarm robotics

Status:

Hypothetical, experimental

Possible applications:

Autonomous construction, space construction

Related technologies:

Swarm intelligence, autonomous robotics, nanorobotics, particle swarm optimisation, multi-agent systems, behaviour-based robotics

Unmanned vehicle

Status:

Research and development, diffusion, commercialisation

Potential applications:

Transport of goods (e.g. food), mass surveillance, eavesdropping, oceanography, commercial aerial monitoring of livestock, mapping of forest fires, pipeline security, home security, road patrols and anti-piracy, patrolling national borders, property reconnaissance and the pursuit of fugitives, exploration and production of oil, gas and minerals, geophysical surveys, geomagnetic surveys, scientific research in areas too dangerous for pilots, such as hurricane and tornado tracking, firefighting, military operations and peacekeeping missions, search and rescue, explosive ordnance disposal, gatekeeping and checkpoint operations, urban street patrols, and police raids in urban areas.

Related technologies:

Unmanned aerial vehicle, AeroVironment, AeroVironment Global Observer, AeroVironment Nano Hummingbird, unmanned combat aircraft, unmanned ground vehicle, unmanned spacecraft, unmanned surface vehicle, unmanned underwater vehicle, autonomous underwater vehicle

Annex 17: Emerging technologies in the transport sector

Airless tyres

Status:

Research,

development,

early prototypes

Possible applications:

Safer tyres **Related**

technologies:

Tweel

Alternative-fuel vehicle

Status:

Commercialisation,

widespread adoption

Potential applications:

Reduction in air pollution Reduced oil

consumption

Strong focus on renewable energy

Related technologies: Electric

vehicle

Hydrogen vehicle

Compressed air vehicle

Autonomous high-speed rail

Status:

Commercialisation

Adoption

Possible applications:

Reduction in air pollution Decrease in

oil consumption

Related technologies:

Electric vehicles, jet

propulsion

Status:

Hypothetical

Possible applications:

Not applicable **Related**

technologies:

Laser propulsion

Electrohydrodynamic propulsion

Status:

Research,

development,

prototypes

Potential applications: Improved

air transport; Efficient

propulsion in the air

Related technologies:

Electrohydrodynamics

Flexible wings

Status:

Experiments,

prototypes

Potential applications:

Control of aircraft and ships

Related technologies: Aircraft flight

control system BAE Systems Daemon

Fluidics and fluidic flight control

X-53 Active aeroelastic wing

Adaptive conformal wing

Flying car

Status:

Early commercialisation

prototypes

Potential applications:

More efficient transport

Related technologies:

Terrafugium transition

Moller M400 Skycar

Urban Aeronautics X-Hawk

Aeromobil

Fusion rocket

Status:

Research and

development

Possible applications:

High-speed interplanetary travel

Limited interstellar applications

Related technologies: Not

applicable

Hoverbike

Status:

Functioning prototypes Early

commercialisation

Possible applications:

Parcel delivery,

search and rescue

Related technologies: Not

applicable

Hovertrain, ground-effect train

Status:

Research and

development

Potential applications:

Higher-speed trains

Related technologies:

Aérotrain

Duke Hospital PRT air-cushion vehicle

High-altitude platforms

Status:

Experimental

Possible applications:

Communications

Related technologies: Not applicable

Jetpack or backpack helicopter

Status:

Early commercialisation prototypes

Potential applications:

More efficient transport

Related technologies:

Not applicable

Maglev or vacuum cleaner

Status:

Research

Early commercialisation

Possible applications:

Higher-speed trains

Related technologies:

Transrapid

Shanghai Maglev Linimo

Maglev

Status:

Research and

development

Commercialisation (maglev)

Possible applications:

High-temperature superconductivity,

cryogenic technology, low-

temperature refrigerators,

Design and construction of superconducting magnets

Fibre-reinforced plastics for vehicles and structural concrete

Communications and high-performance solid-state control systems

Vehicle design (aerodynamics and noise reduction)

Precision manufacturing,

Construction and manufacture of concrete structures

Maglev train

Launch of a maglev-based spacecraft

Related technologies: Vactrain

Levikar

mass driver

Status:

Prototypes

Possible applications:

Not applicable **Related technologies**: Not applicable

Photonic nuclear rocket

Status:

Hypothetical

Possible applications:

Interplanetary travel

Related technologies:

Not applicable Personal commuter rail transport

Status:

Early commercialisation and widespread adoption

Potential applications:

More efficient transport

Related technologies:

Morgantown

PRT Ultra

Photon rocket

Status:

Hypothetical

Possible applications:

Local interstellar travel

Related technologies: Not applicable

Photonics laser cannon

Status:

Prototypes

Possible applications:

Not applicable **Related technologies**: Not applicable

Physical Internet

Status:

Research

Possible applications:

Not applicable **Related technologies**: Not applicable

Scooter-sharing system

Status:

Commercialisation

Potential applications:

Increased density

Related technologies:

Bird (company)

Vactrain

Status:

Research and development

Potential applications:

A faster way to get anywhere

Related technologies:

ET3 Global Alliance

Hyperloop

Fuel Depot

Status:

Research and development

Potential applications:

- Enabling space missions with heavier payloads
- Extending the service life of satellites
- Ultimately, reducing the cost per kg of launch into space

Related technologies: Not applicable

Pulse detonation engine

Status:

- Testbed demonstrations

Potential applications:

- High-speed interplanetary travel
- Potential interstellar travel applications

Related technologies: Not applicable

Reusable launch system

Status:

- Research
- Early commercialisation

Potential applications:

Transport from the surface to orbit

Related technologies:

Falcon 9

Falke Heavy

Starship

New Glenn

Self-driving car

Status:

Research and development

Early commercialisation

Potential applications:

Reducing concerns about driver fatigue whilst driving; useful in countries where hiring private drivers is expensive.

Related technologies: Waymo

Space Lift

Status:

Research and development

Possible applications:

Not applicable **Related technologies**:

Non-rocket space launch Orbital ring

Sky Hook Space Well

Spaceplane

Status:

Research and development

Possible applications:

Hypersonic transport

Related technologies: A2 Skylon |

Supersonic transport

Status:

Commercialisation and

adoption

Potential applications:

Higher-speed commercial aircraft

Related technologies:

Concorde

Tupolev Tu-144 Vehicle

communication systems **Status:**

Research,

development and

deployment

Possible applications:

Informing other vehicles of necessary warnings when

approaching junctions Traffic management

Deployment of ambulances, fire engines and police cars for specific situations such as high-speed chases and bad weather

Driver assistance systems

Automated motorways

Related technologies:

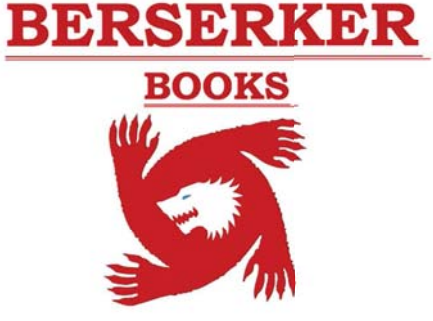
Artificial Passenger

Dedicated short-range communication Intelligent transport system

Table of Contents

Other books by the author
Series by the author Copyright
Bonus
Foreword
Introduction
Acknowledge
ments
Dedication
Epigraph
Table of Contents
Chapter 1: Brain
Implant
Chapter 2: Cyberware
Chapter 3: Brain-Computer Interface
Chapter 4: BrainGate
Chapter 5: Neuroprosthetics
Chapter 6: Remote-Controlled
Animals
Chapter 7: Neural Engineering Chapter
8: Single-cell recording
Chapter 9: Hybrot
Chapter 10: Mark
Gasson
Chapter 11: Visual Prosthesis
Chapter 12: Microelectrode Array
Chapter 13: Cyborg
Chapter 14: Neurotrophic Electrode
Chapter 15: Hippocampal Prosthesis
Chapter 16: Brain Technology
Chapter 17: Stent-Electrode Recording Array
Chapter 18: Chronic Electrode Implant Chapter 19:
Cortical Implant
Chapter 20: Neuralink
Chapter 21: Neural Dust
Epilogue
A Billion Enlightened People

THE PROBLEM: Ignorance is the root of all evil THE SOLUTION: 1BK Community
THE APPROACH: 1BK Factory
THE ACTION: 1BK Moonshot


BERSERKER
BOOKS